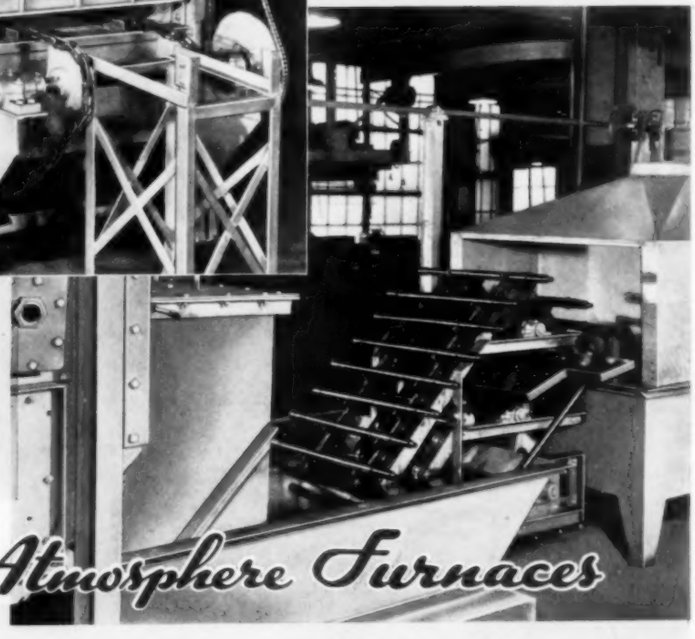
MAR 8 - 1935

Metal PROGRESS

THE AMERICAN SOCIETY FOR METALS

Left—View of clean hardening, automatic quenching and washing machine, and draw furnace.

Below—Automatic mechanism taking axles from oil quench to washer.



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Metal Progress

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Ernest E. Thum, Editor

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Selecting the Proper Hardening Treatment

By H. W. McQUAID
Republic Steel Corp.
Massillon, Ohio

A VERY VALUABLE ACCOUNT OF THE various aspects of pack carburizing was presented in last month's issue by John F. Wyzalek, full of practical suggestions for operators. The present author had previously attempted a similar discussion of the newer process of gas carburizing in METAL PROGRESS for last July. There remains one important phase of this question to round out the whole matter — namely, the adjustment of the details of the carburizing process to bring out the best properties of the steel, both in process and in use. This will be the subject of the present article. Some slight mention will be made of the preliminary normalizing operations, and to make the matter specific, rather than an assortment of beautiful generalities, the case hardening of automotive gears will be considered — something the author has worked with for many years, in his former employment.

We will assume that the analysis has been chosen (or is inherited) from among many of the commercial steels which are giving satisfaction when properly carburized and heat treated. The metallurgist is then immediately confronted with the problem of devising the best treatment of the part to be case hardened, and will find himself considerably confused if he endeavors to translate into practice the recommendations given in the average handbook, or in the available literature covering the subject. What is the best equipment and practice for producing the finished part?

Even the volume of production is a matter which influences the correct answer, for if the part requires a high alloy steel to produce maximum over-all strength, such as we would have in a double treated part of 5% nickel steel, the question of processing and equipment is of less importance than if a lower alloyed or plain carbon part were in high production. This is true because as a rule the higher alloyed parts are made in much smaller quantities, and the amount produced does not warrant expensive continuous heating or other operations. They are usually heated in small furnaces, charged by hand. Furthermore, these parts, due to their higher alloy content, are generally normalized in small furnaces and require a much more elaborate normalizing procedure than do the lower alloyed steels or plain carbon steels.

Normalizing Practice

It is impossible, in an article such as this, to go into great detail about the normalizing and carburizing of the higher alloy parts; many elaborate and expensive methods have been worked out in the various plants in which they are used. It may be remarked, however, that a rather remarkable difference of opinion exists as to how best to do it. A good rule to follow with high alloy (and in fact, with most alloyed steels containing nickel in combination with appreciable amount of manganese and molybdenum) is to heat well above the critical range and to cool relatively rapidly to approximately 1200° F., then cool very slowly from this point to approximately 500° F. Rapid cooling through the upper critical range in this way will reduce the apparent banding, and a very slow cool through the lower critical range will eliminate any hard martensite which is formed from the austenite grains, high in nickel and manganese, which exist just above the lower critical point.

An alternate method of normalizing which gives good results commercially with the higher alloyed steels is to air cool from a temperature well above the critical range and then reheat to approximately 1200° F., holding for several hours, and cool in the furnace.

Either of these methods will produce satisfactory results, although the first is preferred.

Normalizing the lower alloy steels (such as nickel-chromium S.A.E. 3100 series, nickel-molybdenum S.A.E. 4615, 3½% nickel steel S.A.E. 2315, and chrome-vanadium S.A.E. 6115) ordinarily becomes a more simple matter. This is particularly true of S.A.E. 3115 and 6115, which show little tendency to air harden. They can be normalized by heating to 1750° F., cooling fairly rapidly to 1200° F., and from there down in air. In fact, very excellent results have been obtained merely by air cooling these steels from 1750° F.

With the advent of the fine grain, shallow hardening type, it has become necessary to increase the normalizing temperature to obtain structures having the best machining characteristics. This is true because the best machining characteristics are usually associated with a coarse pearlitic structure, and this coarsening is difficult to achieve in the finer grained steels at temperatures below 1750° F.

The S.A.E. 3115 and 6115 types, therefore, lend themselves to normalizing in the continuous pusher furnace, but S.A.E. 4615 and 2315 require more care and slower cooling to produce equally satisfactory results. In some heats of nickel-molybdenum steel, S.A.E. 4615, made under certain melting conditions, it was almost impossible to obtain satisfactory machining by normalizing in a standard pusher type furnace and air cooling directly from temperature. For this reason the preferred normalizing cycle indicated above for higher alloyed steels is to be recommended for S.A.E. 4615 and 2315.

In the case of the plain carbon carburizing grades, it is seldom necessary to normalize. Satisfactory machinability is had in the blanks as forged, unless they were rolled or forged under very adverse conditions.

Single Quench Vs. Double Quench

It is quite easy to find a printed recommendation that the best heat treatment for case hardened parts is to quench directly from the curburizing box, reheat above the critical of the core and quench, then reheat again above the critical of the case and quench, and finally draw at approximately 300° to relieve the stresses that are supposed to be present in the steel. This recommendation is apparently based on the idea that the more often the part is heated, the better the case will be! It is very seldom followed!

It is also recommended in the literature that the next best treatment is to quench directly from the carburizing box to "refine" the core, then to reheat above the critical of the case to refine it. Sometimes it is recommended that the part be cooled in the carburizing box, reheated once above the critical of the case and quenched; in this condition the part is spoken of as having an "unrefined core with a refined case." In most textbooks the least-recommended treatment is to quench directly from the carburizing box and use as quenched.

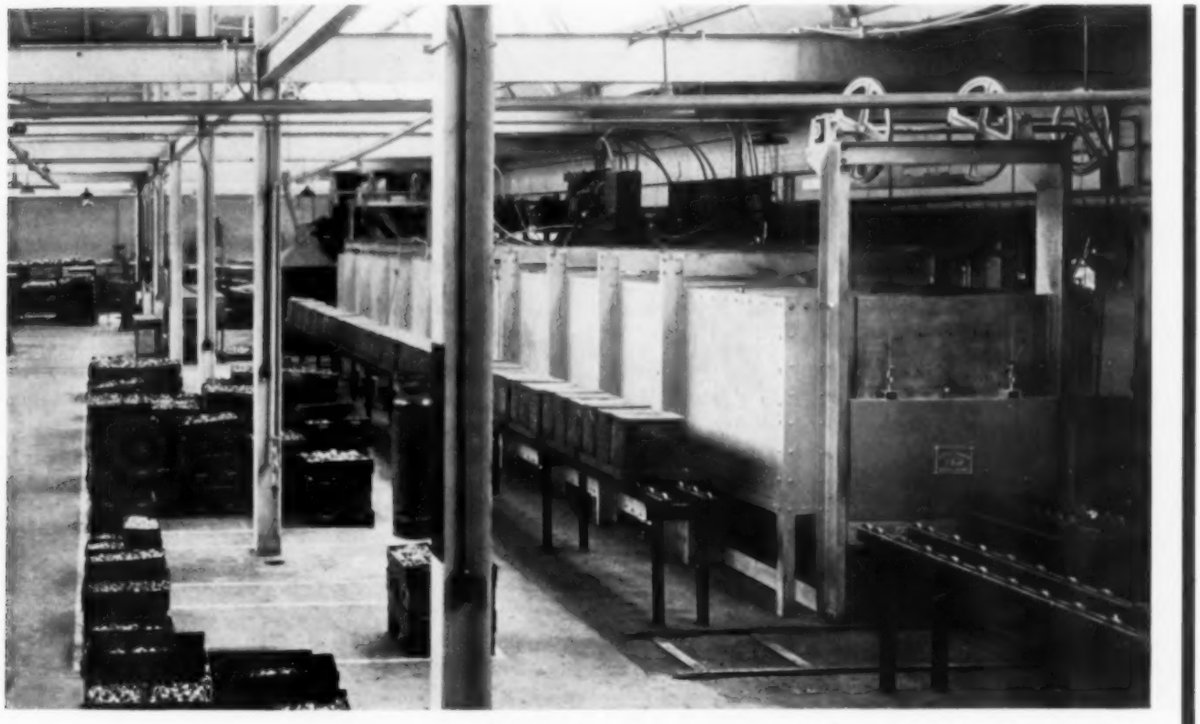
Which one of these treatments is the best, however, and which should be selected for a given part, depends not so much on the quench to "refine" the case and the core, as it does upon the *structure* which is desired in the case, and the over-all properties of the carburized piece. This has been proven to be true of case hardened ring gears and pinions; best life in dynamometer tests and longest life in service have both been correlated with the microstructure of the case, its depth and the characteristics of the transition zone. Any heat treatment — no matter how simple — which will give such a structure will be satisfactory.

One of the most absurd and meaningless phrases used in describing case hardened parts is "a hard case and a tough, ductile core." What we are interested in is the *toughness of the finished part,* including the case, and while it is a simple matter to get the hard case and the ductile core, it is not so simple to get a case with maximum resistance to wear combined with the minimum tendency to localize stresses. We then become interested in the amount of internal stresses in the hardened piece and bump up against the fact that a hard case has high internal stresses, and is often associated with a soft, ductile core.

With the advent of the fine grain, shallow hardening type of steels, it was found that quenching certain analyses directly from the carburizing box would produce structures especially suited for heavy duty gears. For many years (before a full knowledge of the importance of grain size was available) it was customary to quench the chromium-vanadium type of gear steels directly from the carburizing box with quite satisfactory results. With the development

of the fine grain type in other grades of steel, quenching direct from carburizing became common. The reason for this is, of course, that it is not only more economical, but it produces an austenitic-martensitic structure which is considerably more stable under the conditions met in service (that is, has a lower tendency to score in the heavily loaded gears) than the martensitic structure resulting from a quench from lower temperatures.

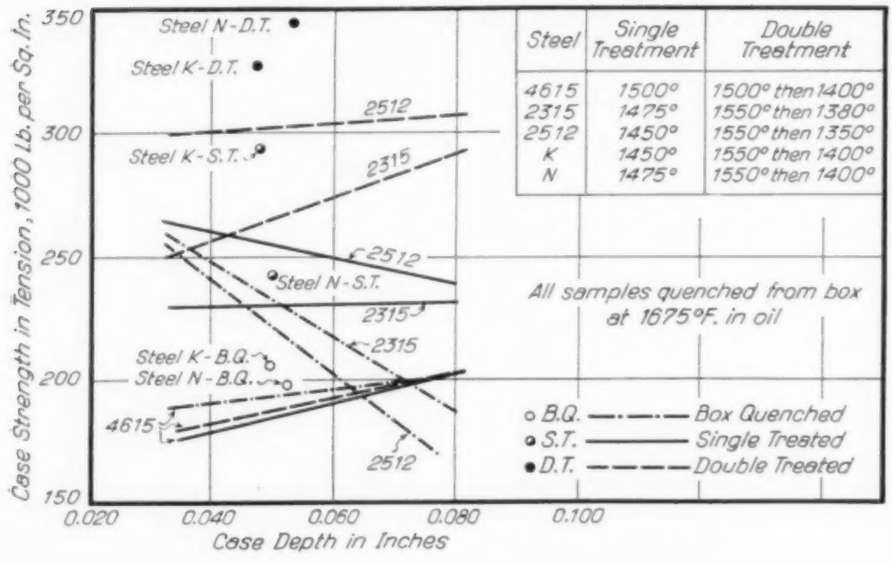
Some of these facts were substantiated in an extensive investigation of case hardened commercial steels, made under the writer's supervision and described in a paper by O. W. McMullen, entitled "Physical Properties of Case Hardened Steels", read before the last annual convention of the American Society for Metals. One of the tests was a special bend test in which the first failure in tension (cracking) could be determined in the case. It will be noted from the figure at top of page 28, taken from that source, that increasing the case depth decreases the case strength in the box quenched samples of S.A.E. 2315 and 2512 (marked *B.Q.*), while with double treatment (*D.T.*) the reverse is true. This difference in strength is believed to be due to the increasing amount of austenite present in the high nickel alloys (3½ and 5%) when quenched in oil from the box at high temperatures (1675° F.). Due to the presence of a martensitic zone beneath the austenitic-martensitic surface, an initial tensile stress is set up in the austenite at the surface because of the greater unit volume of the martensite as compared to the austenite, which reduces the residual strength of the case capable of withstanding external stress imposed by the testing machine (or service).



Counterflow Recuperative Carburizing Furnace in a Bearing Manufacturer's Plant (Courtesy Electric Furnace Co.)

It will be noted that the S.A.E. 2512, when single treated from 1450° F., still falls off in strength with increasing case depth, while the single treated S.A.E. 2315, quenched from 1475° F., increases slightly in strength with increasing case depth. For cases above 0.050 in. deep, S.A.E. 2315 single quenched is stronger than either the 2315 or 2512 box quenched. It should also be noted that the double treated case of S.A.E. 2315 is stronger than the single treated or box quenched case of S.A.E. 2512. These tests also show that the high carbon cases of S.A.E. 4615, 3115, and 6115 have approximately the same strength, and are all weaker than S.A.E. 2315.

In the very heavy cases, however, *when box*



Relation Between Strength of Hardened Case, Its Depth and Its Method of Heat Treatment (After McMullan). All steels were fine grain, carburized to high carbon case, box quenched from 1675° F. in oil. Some samples were then double treated (marked D.T.), others single treated (S.T.), and others not further treated (B.Q.), as shown in the schedule, Krupp steel "K" analyzed 4% Ni, 1.5% Cr, 0.08% C. "N" steel analyzed 3.5% Ni, 0.25% Mo, 0.18% C.

quenched, there is little to choose in strength between any of the analyses. In fact, when the case depth is approximately 0.080 in., the lower alloyed steels may have a definitely stronger case than the higher alloyed steels.

These investigations described by Mr. McMullan proved conclusively that the maximum case strength is obtained with steels of the fine grain type, carburized to give a case which is approximately eutectoid in carbon content. The weakest condition of the case is found in the coarse grained steels, carburized to give a high carbon (saturated) case. While the values plotted in the figure are approximate, they show an unmistakable trend and indicate the most satisfactory heat treatment where maximum strength is required. However, we must sacrifice case strength for stability for many applications where the part in service develops a high skin temperature from the energy lost through friction, or where a maximum resistance to abrasion is of the greatest importance. Therefore, we should not be too hasty in selecting a heat treatment merely on the basis of maximum strength.

Auxiliary Effects

Before selecting a case hardening practice, some of the pertinent and sometimes overlooked fundamentals of the effect of treatment on over-all properties should be firmly fixed in the mind of every metallurgist. They should be familiar with the results obtained by small variations in commercial practice. These may be set down as:

1. The deeper the case, the greater the tendency to warp, and (with the high alloy types) the greater the internal stress in the case when the part is direct quenched.

2. The more nearly the carbon content of the case approaches eutectoid, the higher the over-all strength of the carburized piece.

3. The maximum strength of the case in tension is obtained by double treatment — that is, a reheat above the critical of the core followed by a reheat above the critical of the case, quenched from each temperature in oil.

4. The higher the carbon in the case, the greater the file hardness.

5. The greater the case depth, the weaker the case becomes in tension when the part is quenched directly from the box. This is particularly true of the highly alloyed steels, and is not very noticeable in the commercial treatment of some of the lower alloyed, shallow hardening types, although the tendency exists.

6. For maximum resistance to abrasion, together with maximum stability of case, the higher carbon, fine grain types containing chromium or molybdenum are the most satisfactory, particularly when direct quenched.

7. For maximum case strength, the lower carbon, fine grain types are recommended.

From the above, it is quite obvious that it frequently becomes necessary to sacrifice maximum case strength in order to obtain other properties which are important in the finished part. Since a coarse grained, carburizing grade of gear steel is not recommended in the alloy grades, it is immediately apparent that the control of grain size and hardenability is of primary importance

to the producer of case hardened parts of alloy steels. It is also evident that, since the distortion is primarily controlled by the case depth, the most accurate parts are obtained with minimum depth. It is, of course, dangerous to have cases which are so thin that flaking occurs, and here it should be pointed out that the flaking of thin cases is due to fatigue in the gradation zone underneath the case, and that failure works from the inside out, rather than from the surface in.

The figure on this page is a diagram borrowed from J. G. R. Woodvine's paper in Carnegie Scholarship Memoirs, 1924. It shows the maximum stress in a round bar, tested in bending, from surface to neutral axis plotted as one of the lines OD, OK_1 or OB_3. The minimum depth of case which can be used may be determined from this diagram.

For instance, OA is laid off as 70,000 psi., and a vertical line is drawn representing the fatigue resistance of the 2512 core (double quenched). Similarly a vertical erected at B represents 120,000 psi., the fatigue resistance of the case. Assume the case to be 0.060 in. thick and the diameter of the piece is 0.26 in. (core radius 0.070 in.). The fatigue resistance of the carburized piece is then represented by the line B_3-B_1-A_1-A. If the maximum stress is as represented by OB_3, no trouble need be expected, as these values are all less than the fatigue resistance of the corresponding part. However, if the case were thinner (say 0.040 in.), the fatigue resistance of the part would be represented by the line B_3-B_2-A_2-A, and there is a region in the transition zone, shown as a cross-hatched triangle in the diagram, where trouble may be expected.

This means that the strength in tension in fatigue is more important at the junction of core and case than it is at any other point. To remedy the difficulty at A_1-T, the case should be deepened (line B_2A_2 lowered), the core strengthened (line A-A_1 shifted to right), the piece made larger (line G-B_3 raised) or the stresses lowered (line OB_3 tilted up to O-K_1).

It should be remembered at all times that this diagram applies only in the absence of internal stresses, and hence can only be used for double treated parts (and then with caution). It does explain the common failure by flaking when the case is thin, and indicates the remedies.

It is also apparent that the softer gradation zone and core, lower in carbon, underneath a thin case may be subjected to stresses far above the endurance limit, and fail quickly due to fatigue. This can be overcome by increasing the core strength and also by increasing the case depth. It is quite evident that it is more difficult to increase the core strength of a fully quenched core than it is to deepen the case, but here again we must guard against excessively heavy cases which introduce internal stresses and increase warpage. The proper combination of case depth and core hardness can be determined by a study of warpage; if the heavy cases cause too much trouble from change in shape, it may be necessary to increase the carbon or alloy content of the core to obtain a core which is strong enough.

Surfaces, File Hard

In writing specifications for case hardened parts, it is well to remember that the surface hardness as indicated by the scleroscope, Rockwell, or Brinell tests depends upon the micro-

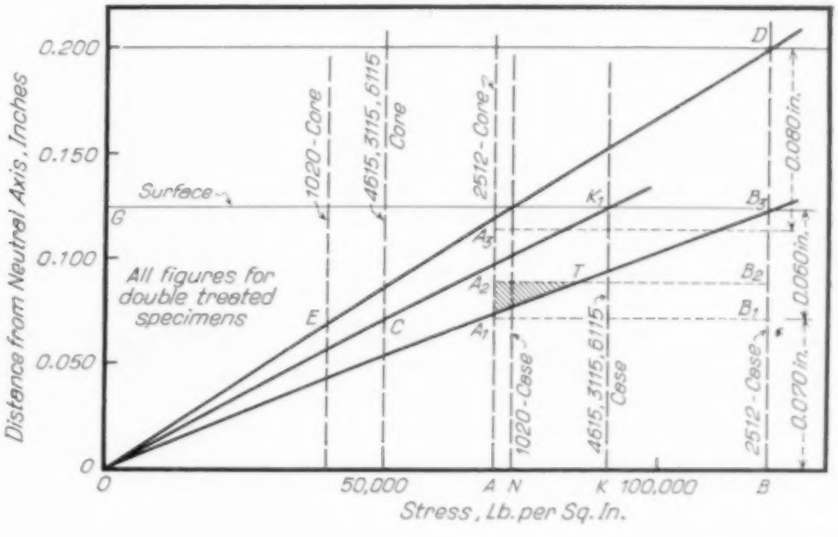


Diagram Showing Fatigue Strength of Case and Core of Various Case Hardened Steels, and Source of Failure in Transition Zone When Bending Stresses Are Too High (After Woodvine). Internal quenching stresses are disregarded, hence the diagram applies only to double treated steels

structure being tested, and is not always related to the file test and to service life.

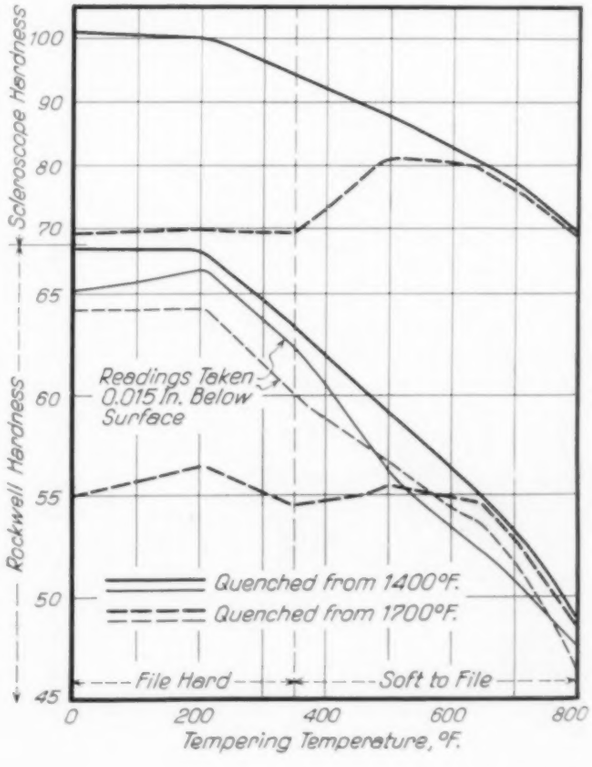
In spite of the shortcomings of the file test, experience indicates that it is the most satisfactory of all tests for the life of case hardened gears. This is especially true of case hardened alloy parts quenched directly from the carburizing box, where the presence of retained austenite lowers the scleroscope and Rockwell readings. It is quite possible (with the right combination of carbon in the case, alloy content, and quenching speed) to produce file hard cases which have a comparatively low Rockwell and scleroscope reading, and service records indicate that the file test is the true indicator, while low Rockwell and scleroscope values have no bearing on the performance. In fact, it seems to be true, particularly with gears and other parts which are subject to heavy abrasive loads combined with consequent high skin temperatures, that the combination of file hardness with low Rockwell or scleroscope indicates the best structure.

It is for this reason that direct quenching has become almost universal for heavy duty, case hardened pinions. The last drawing shows the relation between Rockwell, scleroscope, and file hardness of case hardened alloy parts drawn differently. The curves are for water quenched S.A.E. 3115, but similar conditions exist in practically all carburized alloy steels. It will be noted that when the austenite, retained after quenching from 1700° F., decomposes, there is a considerable increase in the scleroscope readings and a decrease in file hardness. The figure shows that it is possible, with a direct quenched S.A.E. 3115 steel, to retain a scleroscope hardness of 75 by drawing to either 400 or 700° F., while an intermediate drawing temperature will result in a higher scleroscope reading.

It must be remembered also that the amount of austenite retained will increase with increasing case depth and carbon content for a given alloy steel, and hence where you need the maximum Rockwell hardness together with a maximum file hardness in a direct quenched steel, the case should be as thin as service requirements will permit. For this reason, the best combination of minimum distortion and maximum surface hardness in such parts as passenger car transmission gears will be obtained with the minimum case and a high quenching temperature. The carbon content of a case must be as high as possible to obtain the maximum file hardness, but the amount of austenite which is retained in the thinner cases will be decidedly less than in the heavier cases. We have therefore combined a high carbon, file hard, martensitic case containing only a small amount of austenite — a structure which will be at least 85 scleroscope hard. (Just what the advantage of having the scleroscope hardness of 85 really is cannot be stated, since a high scleroscope hardness without file hardness is of no value in a gear, whereas a low scleroscope hardness with a high file hardness produces a very satisfactory gear!)

The above can be reviewed in a few words by stating that with the advent of the new knowledge in melting practice, and the application of grain size and alloy content to the control of hardenability, it has become necessary to alter old ideas as to what constitutes the proper heat treatment for case hardened parts. The new type of alloy steels, with their very much reduced tendency to coarsen in the carburizing operation, and the knowledge of the benefits to be obtained by direct quenching, have made this treatment popular, particularly with the alloy grades.

Effect of Tempering Temperature on the Rockwell, Scleroscope, and File Hardness of S.A.E. 3115, Water Quenched, Showing How to Get a File Hard Surface With a Low Rockwell or Scleroscope Hardness. Quenching temperature either 1700° F. or 1400° F.



Chromel & Alumel; Alloys for Thermocouples

By W. A. GATWARD
Chief Engineer
Hoskins Mfg. Co., Detroit

ABOUT 20 YEARS AGO, WHEN PYROMETers were just coming into general industrial use, there became evident a need for a pair of wires which could be used as a high temperature thermocouple in connection with a rugged portable millivolt meter. In fact, it was not until such a pair of wires was produced that the industrial pyrometer did come into general use. Naturally the wires had to be very heat resistant, but another requirement was that the relation between electromotive force generated at the junction and the degree of heat responsible for it (emf. vs. temp.) must be much higher than that available from platinum thermocouples, then in laboratory use, in order to produce enough current to operate the meter or indicator.

In working with thermocouple wires it is necessary to use some standard of comparison and one really should not talk about a pair of wires as a thermocouple, but he should talk about various wires as referred to this standard of comparison. It has been found that platinum is the best wire for reference purposes.

Nickel is strongly negative to platinum and the alloys of nickel and chromium are positive to platinum. Both nickel and the nickel-chromium alloys are heat resistant and it was quite natural, in developing a high temperature thermocouple, that a combination of this sort should eventually be developed. The curve of electromotive force versus temperature of nickel against platinum, shows irregularities at the transformation point of nickel, namely, about 700° F. Furthermore, nickel itself is quite treacherous as regards embrittlement when exposed to furnace gases. A great part of the early development was on an alloy wire to overcome these difficulties. The resulting alloy known as "alumel" consists of about 95% nickel with additions of manganese, silicon, and aluminum.

For the positive wire, the "chromel" which was eventually chosen contained approximately 90% nickel and 10% chromium. It yielded almost the maximum positive emf. against platinum that any alloy in this binary system could produce.

The emf.-temp. curve of chromel vs. alumel which covered the range from 32 to 2500° F. was remarkably straight. In fact, it was so regular that it could almost be considered a straight line. Furthermore, the emf. was sufficiently high that the millivolt meters being used at that time made very satisfactory portable pyrometers. The alloys also proved to be relatively inexpensive.

The original electrical data on chromel-alumel couples were published about 1915. All through the rapid metallurgical and industrial development since that date more and more instruments were sold and greater accuracy was demanded by the pyrometer manufacturers and users. Naturally the prime obligation on the part of the makers has been to maintain the millivolt values originally established so that control equipment already in use could be retained.

Manufacturing Limitations

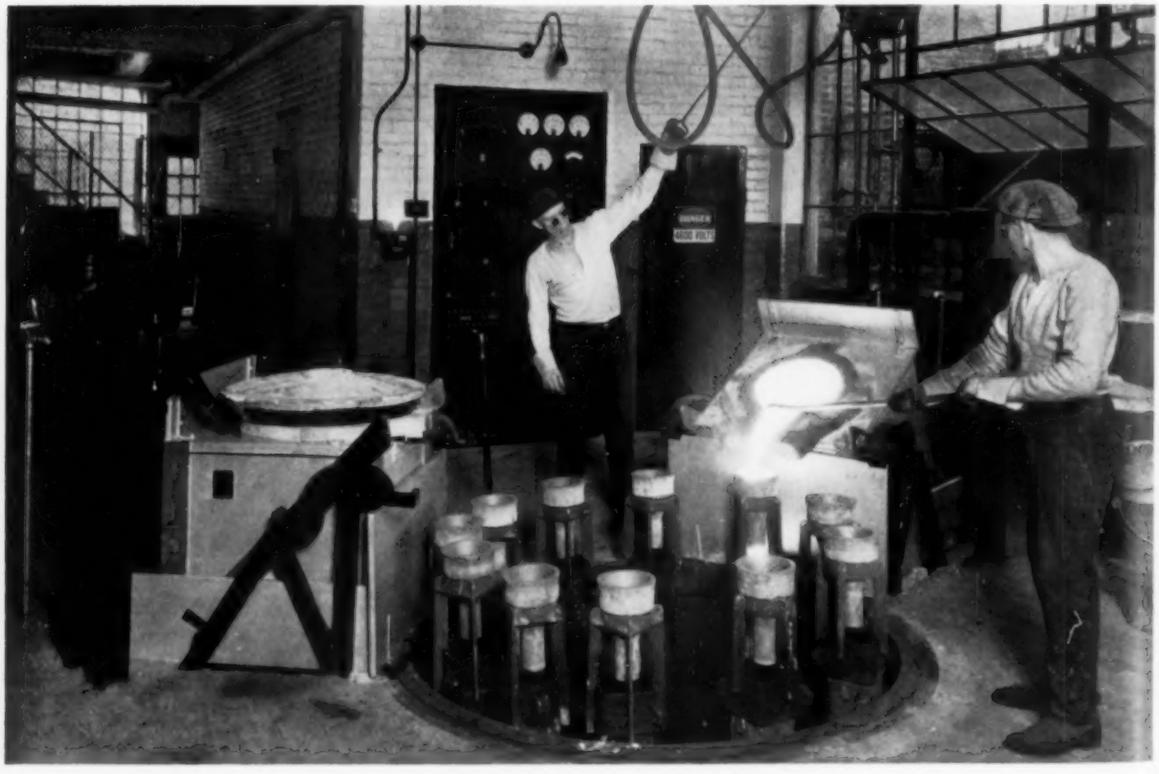
The production of the thermocouple alloys chromel and alumel therefore presents a most unusual metallurgical problem. Both of these alloys may be classed as heat resistant, but they must be treated differently from other modern heat resistant alloys, for their industrial value

and widespread use is based on physical properties, the values of which were established many years ago and these physical properties must be maintained as standards for many years to come.

The original chromel and alumel alloys were melted in small heats in a carbon resistor type of furnace from virgin raw materials. The raw material of that time was not as uniform as it is now and even with the greatest of care, it was not possible to duplicate the electrical characteristics closely enough, even to satisfy the relatively easy specifications of that day. To get around this difficulty the alloys were classified so that if a heat of chromel tested higher than the desired value, it was matched up with a heat of alumel which tested lower than the desired value by the same amount. This resulted in a series of classes which, in the early days, was quite cumbersome.

In the manufacture of the usual industrial alloys, the metallurgist is free to adopt the most modern or most desirable production methods and he may manipulate old or newly discovered ingredients in any way he sees fit in order to raise the standard of quality of the alloy. In other words, so long as each heat is better than the previous one, he is quite content. For most alloys the quality is judged by its ability to yield higher values in various physical tests, such as strength, corrosion resistance, resistance to oxidation or what not. On the other hand, any modification in the metallurgy of thermocouple alloys must be very thoroughly tested before adoption and some otherwise desirable changes cannot be made at all because they would produce material which would deviate from the standards mentioned above.

In response to the above considerations the published emf. values have been slightly changed twice in 20 years. Unavoidable changes in raw material have been responsible for most of this modification, but slight inaccuracies in the original work have also been eliminated. When it was first discovered that the alloys were not producing emf.'s called for by the standard curve, the most desirable thing would have been to modify the alloys so as to make them produce the proper values. This was attempted, but it soon developed that under the existing conditions of melting and with the available raw material, the published curve did not truly represent the alloys. A change in the basic standard was there-



Pouring a Heat of Chromium-Nickel Alloy "Chromel" From High Frequency Induction Furnace. Note pouring thimbles mounted on each ingot mold. Bottom of casting pit is a turntable

fore made in 1927 and, as modified, the curve was continued until 1932. By 1932 the present modern induction method of melting was available and raw material had been firmly standardized, and it seemed that the time was ripe for a reappraisal of the situation. Therefore 50 heats of each alloy were prepared under carefully controlled conditions, such as would duplicate the original alloys, and the U. S. Bureau of Standards undertook the very difficult task of determining the average shape of the curve of electromotive force vs. temperature of this large number of samples.

This investigation resulted in the curve adopted in 1932. Full details may be had in Bureau of Standards, *Journal of Research*, March, 1932, in the paper by W. F. Roeser, A. I. Dahl and G. J. Gowens. These values are now standard throughout the world. All scales and charts in existence prior to 1932 were designed on the basis of the original couple data. The use of metal melted since 1932 yields just as good accuracy on these old scales as was obtained prior to 1932, but, to obtain the accuracy of which the present-day couples are capable, scales should be remade to agree with the data of 1932. The table on this page shows the original (1915) data at definite temperatures compared with the similar data adopted in 1932, and now the standard.

Millivolt Equivalents for Chromel-Alumel Thermocouples
(Cold End at 32° F.)

Temperature °F.	Original Data (1915)	B. of S. Data for 1932	Change in Millivolts
100	1.50	1.52	+.02
200	3.90	3.82	—.08
300	6.22	6.09	—.13
400	8.45	8.31	—.14
500	10.72	10.56	—.16
600	13.00	12.85	—.15
700	15.25	15.18	—.07
800	17.60	17.52	—.08
900	20.00	19.88	—.12
1000	22.30	22.25	—.05
1100	24.70	24.62	—.08
1200	27.00	26.98	—.02
1300	29.30	29.33	+.03
1400	31.60	31.65	+.05
1500	33.90	33.94	+.04
1600	36.20	36.20	zero
1700	38.45	38.43	—.02
1800	40.60	40.62	+.02
1900	42.70	42.77	+.07
2000	44.80	44.89	+.09
2100	46.90	46.97	+.07
2200	49.00	49.01	+.01
2300	51.06	51.00	—.06
2400	53.05	52.95	—.10
2500	55.08	54.85	—.23

Temperature-Millivolt Equivalents at Low Temperatures
Chromel vs. Alumel; Cold End at 32° F.

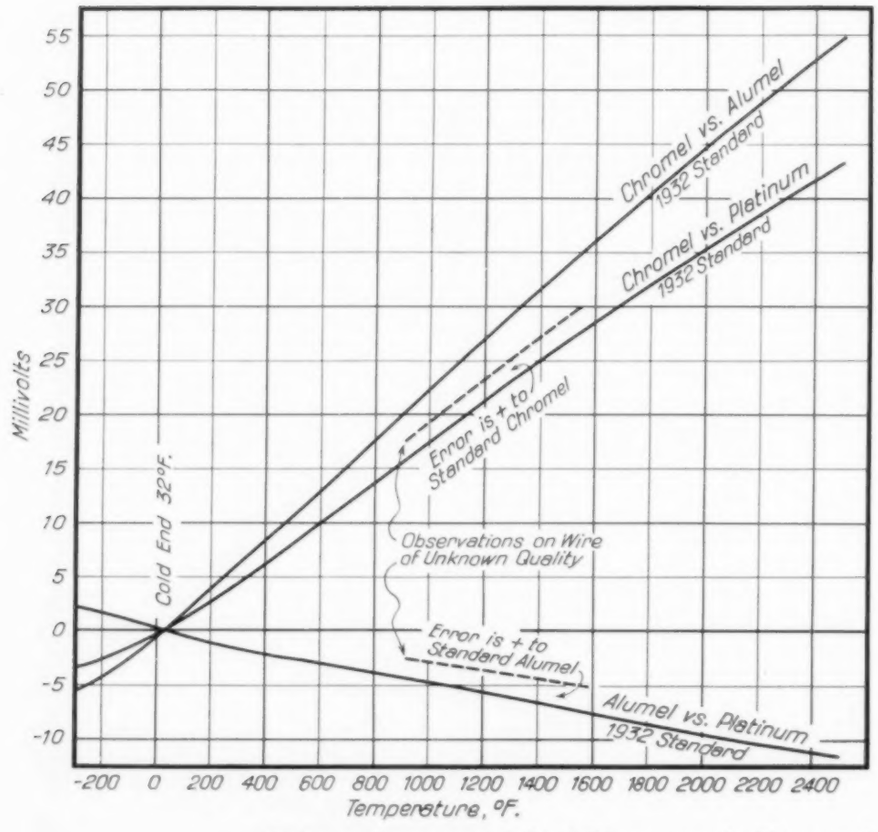
Temperature Degrees Fahr.	Millivolts	Temperature Degrees Fahr.	Millivolts	Temperature Degrees Fahr.	Millivolts
32	zero	—80	—2.28	—200	—4.29
30	—.04	—90	—2.47	—210	—4.44
20	—.26	—100	—2.65	—220	—4.57
10	—.47	—110	—2.84	—230	—4.71
0	—.68	—120	—3.01	—240	—4.84
—10	—.89	—130	—3.19	—250	—4.96
—20	—1.10	—140	—3.36	—260	—5.08
—30	—1.30	—150	—3.52	—270	—5.19
—40	—1.50	—160	—3.69	—280	—5.30
—50	—1.70	—170	—3.84	—290	—5.41
—60	—1.90	—180	—4.00	—300	—5.51
—70	—2.09	—190	—4.15	—310	—5.60

During the investigation at the Bureau of Standards, the millivolt equivalents were also determined down to —310° F., and these values are presented in the same table. While the emf. available from the couple at —300° F. is only 5.51, nevertheless with modern methods of measuring potentials such a thermocouple becomes a very useful device for measuring very low temperatures at inaccessible locations.

The problem of testing the thermal emf. of thermocouples is a highly specialized task; some idea of it will be given a little later. Enough has already been said to indicate that the alloys have been and are being manufactured to a very high order of uniformity. The result is that if the user applies them with intelligence, satisfactory service will result.

Precautions in Use

The couples yield best results in an oxidizing atmosphere and should never be used in reducing atmosphere. The oxides of both alloys are preferentially reducible, and the presence of any reduced nickel on the surface of an alloy wire is a certain source of trouble. There is bound to be a temperature gradient along the wire when in



Relation Between Standard Thermocouple Wires and Platinum (Which Is Zero). Dotted lines show that errors cancel if of same amount and same sign

use and if they are covered with even a small amount of reduced nickel, circulating parasitic currents will be developed flowing counter to the main thermocouple current.

It has been found for extreme cases of reducing gases above 2000° F. that the highest grade of refractory protection tube must be used, as there is no known metal tube which will give sufficient protection. Below 2000° and down to about 1600° F. nickel-iron-chromium protection tubes are usually adequate. For the low temperatures, iron tubes have been successfully used, but the maximum temperature at which they will give adequate protection is about 1400° F. and at such a temperature it is more economical to use tubes of heat resistant alloy.

To get the most accurate results with chromel-alumel thermocouples, it is necessary to use the same alloy wire leading up to the recording or indicating instrument. This is quite evident when we consider the situation at the cold end of the thermocouple. At this point there are two junctions and naturally these will be thermocouple junctions if the lead wire is not the same material as the thermocouple. Theoretically it would be possible to produce a pair of substitute wires which would develop the same emf. at temperatures likely to be reached at the "cold" end, but practically this has never been done.

Other precautions for use may be derived from a careful reading of the following brief outline of test methods.

Testing of Wire

There are three methods of testing thermocouple wire and all of them have limitations. The "unknown" wire, that is, the wire being tested, can be welded to a length of platinum wire of the proper purity and not contaminated in any way. The couple thus formed can then be checked at the known melting points of various materials. This method is the nearest to a fundamental method, but it is cumbersome and tedious and requires considerable care in the selection of crucibles and metals of known melting points.

Another method implies the use of a platinum thermocouple of known and established accuracy and one which can be maintained as to accuracy. In this method, the tip of the platinum thermocouple is connected to the end of the unknown wire by a short piece of platinum wire, say ½ in. long. This combination is then inserted in a suitable furnace, the temperature of which is measured by the platinum couple. The emf. of the unknown wire against the pure platinum wire is then measured at this temperature. (A convenient way is to use two potentiometers, so that simultaneous readings can be taken on the platinum couple and on the unknown wire. If two potentiometers are not available, one is sufficient, providing the temperature can be maintained steady for a few moments.) This method is all right in the hands of an expert, but the operator has a serious responsibility in making this sort of a check. The furnace must have an oxidizing atmosphere and great care must be

used to avoid any gas entering the furnace such as might be given off from asbestos insulation or asbestos string. The cold ends must be maintained exactly at 32° F. or some other known temperature, and the platinum thermocouple standard must be checked very frequently against other standards to be sure that the temperature of the furnace is accurately known.

A third method of testing unknown wires involves the use of a wire of the same material which has been standardized by one of the preceding methods. This method is perfectly reliable and on the average will yield more accurate results. In conducting this test, the unknown wire is simply welded to the known wire and inserted in a furnace which does not need to be closely held to any particular temperature. In other words, if the test is wanted at 1600° F., the furnace can be within 50° of this.

Precaution must again be taken as to contamination by furnace gases. In testing a piece of unknown wire, it is well to measure its emf. against its standard on a rising heat and it is also advisable to use a No. 8 gage wire as a standard, because such a wire is self supporting in a furnace and will stand more abuse than the finer sizes of wire. If the standard wire is heated to a temperature above 2000° F., it is advisable to cut off the part which had been heated before another test is made, so that in case the standard has been contaminated, the bad part will be removed before any assumption is made as to its condition. The cold ends of the wires must be kept at the same temperature (which can be that of the room). The only precaution is to be sure that these cold ends are protected from radiated heat or drafts. The samples may be connected to the measuring device by copper leads.

Since the value of the unknown wire is unknown at the beginning of the test, it is convenient to use a measuring instrument with a zero in the middle part of the scale. A millivolt meter giving a full scale deflection on 10 millivolts is perfectly satisfactory for this sort of a test and in case it does not have a center zero, then the needle can be adjusted to stand directly over the one millivolt figure. Under these conditions no matter whether the unknown wire is plus or minus to the standard, the reading can be made. The standard wire should always be connected to the negative binding post.

There is apt to be some confusion in measuring the errors of these two wires against their standards and the sketch on page 31 has been drawn with the idea of explaining the standard method of marking these thermocouple wires. When considering chromel against its standard, if the departure is positive, then the wire has a plus error and this error would cause the thermocouple to read high. This is quite simple and logical. When dealing with the alumel, if the unknown wire is positive to its standard, this error would cause the thermocouple to read low and, as seen from the curves, the emf. of the alumel against platinum would be less than it should be. This means that if both wires have the same sign and the same amount of error against their standards, then a thermocouple made from these unknown wires would have no error at all, and no correction to be applied. In other words, if the errors have the same sign, they tend to compensate and if at the same time they have the same magnitude, then they *totally* compensate. For practical purposes, an error of 0.1 millivolt on either wire will cause an error on the thermocouple of approximately 4½° F.

Method of Testing Several Samples of Wire of Same Alloy, by Comparing the E.M.F. of Each Against a Standard, to Which They Are Welded

Relation of Impact and Tension Tests of Steel

By H. C. MANN
Research Engineer
Watertown Arsenal

IN ORDNANCE PRACTICE THE NOTCHED tension type of impact specimen is specified for the inspection of certain classes of forgings, and such impact values (when considered together with static tension tests) have been extremely valuable in determining the acceptability of material for severe service. Since our beliefs in this matter are at variance with those held by a number of competent metallurgists throughout the metal industry, it would be desirable to outline the facts which have convinced us.

Conclusions stated at a symposium on impact testing held by the American Society for Testing Materials in 1926 may be taken to represent the present-day status of the impact test (on notched bars, broken transversely) from a commercial standpoint:

1. The results are not sufficiently accurate and discriminating to indicate any but rather large differences in materials.
2. The results are in terms not applicable for use in design.
3. The results are not comparable between different types of machines.

In the present general state of knowledge, it may well be stated that very little is known as to what impact values really mean. They are undoubtedly susceptible of discriminating between correctly and incorrectly heat treated materials, but the results are far from acceptable as a definite measure of serviceability. In the notched bar test, the notch is used to locate the point of fracture, and the results obtained are largely dependent on the *form* of the notch. Even when such tests are made with extreme care, duplicate tests often give widely different results, and present a serious question as to how far they should be relied upon to differentiate between the physical characteristics of different materials.

Variations in Methods and Equipment

Unquestionably, one of the greatest influences retarding the impact test has been the general use of a wide variety of shapes and sizes of both notch and specimen, each giving a new series of impressions as to the interpretation of the results obtained. Therefore, from the earliest investigations of this subject, attempts have been made to correlate impact strengths with some physical characteristic of the static tension test. While no definite results were obtained, these investigations brought out the following important facts:

1. A material has the capacity of absorbing only a limiting amount of energy per unit of volume.
2. A material possesses a definite limiting rate of energy propagation or absorption.

Another handicap of the notched bar impact test is that of variability in the testing machinery. Unlike the tension, or static test, wherein the physical characteristics brought out by any of the several available types of testing equipment are essentially the same, the dynamic, or impact test, yields a wide divergence in results because of the varying forms of specimens and methods of load application used.

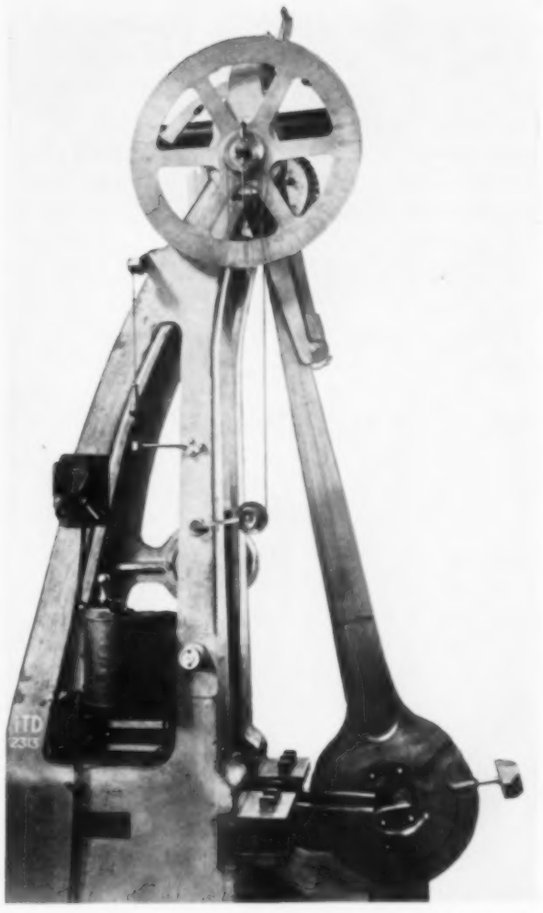
We will assume that the reader is sufficiently familiar with the operation of the pendulum type

Approved for publication by the Chief of Ordnance, U. S. Army

of machine, so that only the merest mention of the two principal designs shall be made. In the Izod machine the specimen is placed in an upright cantilever position and the projecting end is hit by the swinging pendulum. In the Charpy machine the notched specimen is supported at both ends and the pendulum strikes it directly opposite the notch.

The fixture for testing specimens in tension impact is less well known, and as it is the one which will be discussed in what follows, it is shown in the adjoining figure, where it is attached to a Charpy machine.

When testing for impact in tension, one end of a tension specimen is screwed into the back edge of the pendulum, the other end having been screwed into a crosshead or tup. When the pendulum reaches the lowest position of its swing this crosshead strikes a pair of horns or projections attached to the base of the machine, stopping the forward movement of the tup and allowing the kinetic energy in the pendulum to stretch out and rupture the specimen. The energy absorbed by the specimen is calculated as the difference between the available kinetic energy of the swinging pendulum and its attachments at the instant of impact, and the kinetic energy remaining after rupture, as measured by the angle it swings past dead center.



Charpy Machine With Pendulum Approaching Bottom of Swing. Note tension test piece screwed into rear of hammer-head. The bar or tup at the rear end of the test piece will strike the ends of the horns projecting from the anvil at the base of the machine, and the test piece will be broken by the energy of the swinging pendulum

Effect of Volume and Speed

Two principal factors affect the impact test, namely, the volume available for the absorption of energy (as determined by the length of section at the least diameter), and the velocity of the applied force.

The effect of volume on the total amount of energy absorbed is best illustrated by tension impact specimens. The specimens shown on page 38 were both 0.505 in. diameter; one was 2.5 in. and the other 5.0 in. between shoulders. The volume participating in the absorption of energy in the longer one (represented by the length of uniform least diameter) was therefore twice that of the shorter. The 2.5-in. specimen absorbed approximately 1300 ft-lb. of energy and was ruptured. The 5-in. specimen absorbed the total energy capacity of the machine, about 2100 ft-lb., and merely stretched.

These results indicate in a greatly magnified form the general results which may be expected of notched specimens, where the volume, as determined by the length of uniform least diameter or cross section, is very small, and where slight variations in notch dimensions can readily result in wide variations in volume, as so measured. This, coupled with the fact that the notch location is arbitrarily selected without previous knowledge as to the conditions of the material in that particular location, must necessarily lead to the large inconsistencies.

When different types of impact machines are in use, the velocity at impact must also be considered. For instance, the operating impact velocity normally encountered in an Izod machine is 11 ft. per sec.; in a 30-kg-m. Charpy machine it is 16 to 18 ft. per sec.; and in a 300-kg-m. Charpy machine it is 32 ft. per sec. English investigators were among the first to recognize the effect of change in impact velocity, but lim-

ited themselves to unsuccessful attempts to correlate the results of different machines. German investigators have shown that materials possess the capacity to absorb a certain amount of energy per unit volume, and have shown that this amount varies with the change in impact velocity. In practically all of these investigations, however, notched bars have been used, and it is most difficult and laborious to determine the volume — a matter utterly impracticable for routine testing. Furthermore, existing machines are not suited for changing the velocity as desired, to any great extent.

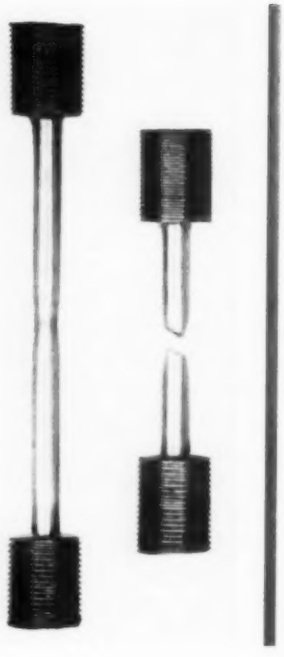
Regardless of the type of impact machine employed, the essential result of the test is a measure of the amount of energy absorbed by the specimen in undergoing deformation and rupture. It should be obvious that if it is desired to draw any comparison between the static and dynamic tests, the same essential data must be recorded in each case, and to record these data, it is necessary that similar specimens be used. The type which lends itself most readily to both the static and dynamic tests is the tension specimen. This specimen can be made of such form that the volume participating in the absorption of energy can be easily calculated, and at the same time allow for comparisons of the values for elongation and reduction of area under both conditions of test.

Energy Absorbed During Testing

Considering the static and dynamic tests independently, we find that in the static tension test the energy absorbed, or "work value," is obtained from a load-elongation diagram constructed from data recorded during the test. In the dynamic test the energy absorbed (the work value) is calculated from the difference between the initial kinetic energy and that remaining in the pendulum after the specimen is ruptured. When so computed from the ordinary stress-strain diagram, the work value obtained from a static test is always considerably less than that of the dynamic test on similar specimens of the same material.

Let us consider the cause of this discrepancy.

In both static and dynamic tests the specimen is subject to external forces, and while the condition or state of the specimen is changing, work is done against these forces. This work consists of two forms — *(a)* the work of deformation, and *(b)* the work which manifests itself in the form of heat. In the dynamic test the considerable degree of heat developed is clearly evident to the touch, whereas the static test is carried out so slowly that the heat is dissipated and its presence hardly noticed.



Illustrating the Effect of Volume of Specimen on Impact Strength. Both test pieces were of same diameter, but one twice as long as the other. The shorter one absorbed 1300 ft-lb. of energy and broke; the longer one absorbed 2100 ft-lb. of energy, & did not break

In the dynamic test only the total value of energy absorbed is obtained. However, we know that the specimen is deformed, and that a considerable degree of heat is developed during the test. Therefore the total value of kinetic energy must have been expended in performing the work of deformation and in producing a rise in temperature of the specimen. The equation for this work may be written as follows:

$$\delta Q = \delta W + \delta U$$

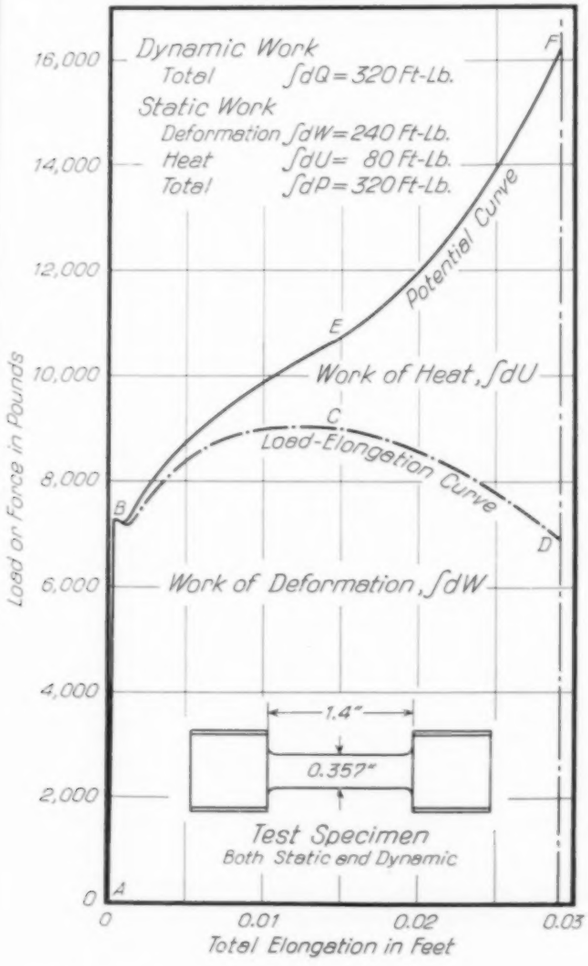
where δQ is the total kinetic energy, δW is the work of deformation, and δU is the work equivalent of the heat produced.

When the static test is performed so as to collect data for the stress-strain curve, the progress of deformation to rupture consists of a series of steps; the load is applied until the specimen has elongated a certain predetermined amount at which point the loading is stopped and held until no further movement of elongation is noted. When this so-called balance is attained, the elongation and load values are recorded, and from these data the load-elongation or work diagram may be constructed. This is the curve *ABCD* of the figure on the opposite page, and is in fact a load-elongation curve, and corresponds to the stress-strain diagram when the data are figured to pounds per square inch of original section and

elongation in percentage of the gage length.

In this method of loading, it has been observed that in passing through each increment of elongation (which may be referred to as Δe) the actual applied load required to produce this movement is greater than that recorded when the limit of the distance Δe is reached and balance is attained. The difference between these two load values depends on the rate of loading; when the load is very slowly applied there is very little difference between them, but as the rate is increased, the difference becomes of considerable magnitude, the load to produce a given movement Δe being much higher than the load at final balance.

Upper Curve Is Plotted From Data Figured From Reduced Area of Specimen Under Load; Lower Curve Figured on Original Cross-Section. Area under potential curve corresponds to impact strength in tension; area under lower curve is the work of deformation; area between curves is mechanical equivalent of heat produced by internal friction in metal



It has also been observed that during this movement Δe, the temperature of the specimen appears to increase with the rate of loading; when the loading is stopped to attain a balance, the load value decreases as the heat is dissipated, until the normal temperature of the specimen is reached.

Two Forms of Work Done

This indicates that two forms of work are done in stretching the specimen a small amount Δe, namely *(a)* work of deformation and *(b)* work equivalent of the heat produced. Their sum represents the mechanical potential energy of the specimen, which theoretically is a function of the elastic strength. By reason of the cold working effect, the elastic strength (and therefore the mechanical potential energy) is continually increasing to the point of rupture. Therefore for each increment of elongation, Δe, higher elastic strength values are produced, the summation of which must equal the total mechanical potential energy of the entire process of deformation to rupture.

Values of elastic strength can readily be obtained during the test. They are plotted in curve *ABEF* on the diagram alongside. Data for this curve were obtained by applying the load to produce definite increments of strain, stopping to allow the load and strain to come to rest, then measuring the diameter of the reduced section. The recorded load was increased a proportional amount to the reduction in area. The curve so plotted may be called the "potential curve"; it is of quite different shape from the conventional load-elongation curve *ABCD*.

Since the values for the load-elongation curve *ABCD* were obtained at normal temperature, the area under it represents the integrated work of deformation. Likewise the area under the potential curve *ABEF* represents the summation of the mechanical potential energy. The difference between these areas then represents the work equivalent of the heat produced.

Potential curves for a number of materials in various conditions, cold worked and heat treated, have been drawn accurately, the area measured, and found to agree with the energy required to break the tension specimen in impact. Experiments have also been made to evaluate definitely the heat generated during a "static" tension test.

Fine iron and constantan wires were spot welded to the surface of diametrically opposite sides of the test specimen at increments along the entire gage length. The specimen then acted as the junction point of a thermocouple and it

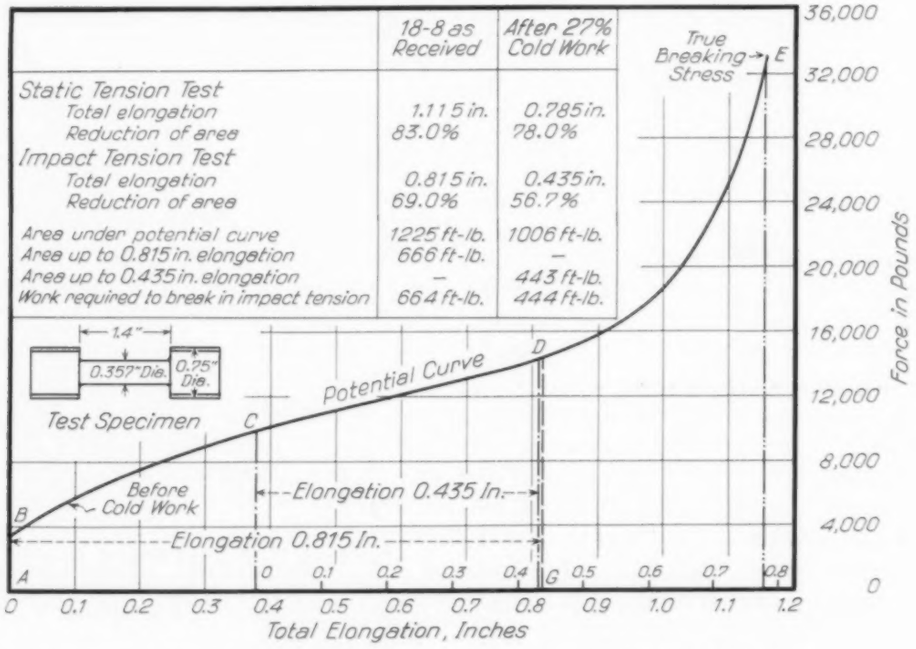
was readily possible to measure the actual rise in temperature during the impact test. The rise in temperature, when integrated in terms of ft-lb., was found to equal, within allowable experimental error, the energy value obtained from the difference between the load-elongation and the potential curves of the static test. It is of interest to note that the rise in temperature along the gage length was found to vary inversely as the area of the reduced section, the maximum at the point of break being 467° F.

The table on page 41 shows static and impact values obtained from metals of several compositions. It will be noted that in most cases the values of both static and dynamic tests are equal, within allowable experimental error. However, a few show difference of sufficient magnitude to indicate they must be due to some as yet unconsidered cause. An explanation of this discrepancy was discovered from comparative tests of stainless 18-8 steel.

Stainless Steel Is a Special Case

The curve below shows potential curve *ABCDE* obtained from a rolled bar, 2⅜ in. diameter, of 18-8 as received, and *OCDE* after longitudinal stretching cold to an equivalent of 27% and soaking at low temperature to relieve residual stress. It will be observed that the cold worked bar carries a load of 100,000 psi. before sharply yielding; the potential curve from this point on *(CDE)*, however, is identical with the upper part of the curve for the material as received. Static and dynamic tests, either of the as-received or cold worked conditions, showed that much less energy was absorbed in the dynamic tests than calculated from the areas under the static potential curves, and that the values for elongation and reduction of area were likewise reduced. This indicated that something had prevented the material from absorbing in impact the maximum amount of energy possible.

It is believed that the progress of deformation to rupture is the same in both static and dynamic tests, and therefore the elongation of the specimen broken in the dynamic tests (both as received and cold worked) was laid off as lines *DG* on the abscissa of the potential curves. It was then found that the energy represented by area *ABCDGA* was practically exactly equal to that absorbed in the dynamic test of the as-received bar. (The same was found for the cold-worked specimen.) It was therefore concluded that the velocity of impact was too high for maximum energy absorption.



Potential Curve of 18-8 as Received Starts at A; of Cold-Worked 18-8 Starts at C. D-G represents limits of elongation in tension impact. Areas under curves up to D-G check breaking strength in impact tension, determined in Charpy machine shown on page 37

To further investigate this point a series of tests was carried out on 18-8 and on an armor plate that gave the same energy values in both static and dynamic tests, to determine the effect of impact velocity, or time factor. The results of these tests are shown on the last curve. Velocity was changed by varying the height of fall of the pendulum. Due to its mass, lower striking velocities than 6 ft. per sec. could not be obtained, and still have sufficient energy available to rupture the specimen.

These curves indicate that stainless 18-8 is a steel which, while it can absorb large amounts of energy at low velocities, has its energy-absorption rate rapidly reduced as the velocity of impact is increased. The other material tested showed no change in energy absorption up to the limit of 32 ft. per sec. obtainable from the testing machine, and indicates that while it cannot absorb

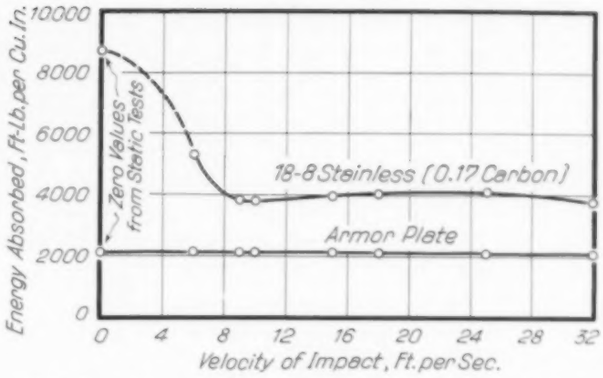
Comparison of Static vs. Dynamic Tests
Steels of Varying Composition

Steel	Static Calculated from Area Under		Dynamic Tensile Charpy at 32 Ft./Sec. Velocity
	Elongation Curve	Potential Curve	
A	250 ft-lb.	373 ft-lb.	301 ft-lb.
B	244	344	346
C	260	365	362
D	241	356	278
E	249	365	308
F	242	293	293
G	207	257	257
H	960	1225	664
I	932	1006	444
J	240	320	320
K	304	455	454

anywhere near the maximum amount of the 18-8 steel, its capacity is not diminished by increasing velocities.

Significance of Impact Test

These results are considered indicative of what may be expected of materials when tested under conditions of variable impact velocities. It is believed that these test methods offer a clue to the true significance of the impact test, since the results obtained are understandable, are in terms applicable for use in design, and are capable of closely discriminating between materials. Impact testing at variable speed should open up a heretofore unexplored field, and eventually result in material whose energy absorption at given velocities can be specified — a real step toward the prevention of failures in service, and the development of further useful properties in various metallic materials.



18-8 Can Absorb Much More Energy at Low Velocity Than It Can at High; Armor Plate, on the Other Hand, Is Insensitive to Variations in Testing Speed

The impact at variable speeds, in combination with the static potential curve, should completely determine the dynamic and static properties, from which subsequent behaviour of a material under known service conditions can be definitely predicted. The static potential curve, in addition to yielding maximum energy absorption values, offers an extremely simple method for pre-determining the increase in elastic strength produced by varying percentages of cold working, either by rolling, drawing, or other cold working process. Also, the true value of the breaking stress obtained from this curve is intimately associated with the material's microstructural characteristics, and thus may be used as a measure of heat treatment efficiency. Lastly, it is believed that this type of test will materially aid in solving many of the problems now encountered in the automotive, railroad, and other fields where both static and dynamic forces are involved.

Although considerable time is required to obtain data from which to plot a true-stress curve, its practical use has been found to be well worth the extra time consumed. Likewise, it should be possible to construct an impact machine having striking velocities considerably higher than either Charpy or Izod (Messrs. Greene and Luerssen have shown the way in their work on torsional impact.) Correlation of these results will do much to interpret anomalies associated with the tension test, and which are now roughly indicated in variations in the appearance of the fracture.

Creations in Stainless Steel, Displayed at Industrial Arts Exhibit, Metropolitan Museum of Art, New York, and Sponsored by Electro Metallurgical Co.

Come and Get it!

Editorial Notes

Breakfast Sets and Bridge Prizes

OBSERVE the breakfast set made of stainless steel! The Editor, being a lover of beautiful things, especially if made of metal, coveted a set of this sort, and inquired the price. Only $500.00, thank you! (No, there is no typographical mistake; the decimal point is in the right place.)

Now, we protest that price. We are inclined to think that it will restrict the sale of these breakfast sets. We believe that such asking prices will put an entirely false idea into the minds of the millions of ultimate consumers of stainless steel utensils; it ranks the raw material in competition with silver and gold instead of with copper and aluminum, where it belongs.

No doubt the artist who has the ability to shape these interesting forms should be paid handsomely for his creation. But we would like to see some fabricating company buy him out, so to speak, and put these pieces into quantity production so that thousands of homes can be graced with beauty now reserved for the sinful rich. It should be good business for some steel manufacturer to press this matter, for breakfast sets at $500 consume no tons of stainless steel.

Anyone who thinks the public will not appreciate and buy beautiful things of metal, when they are priced right, should consider the success of Chase Brass Co., which has secured some good designs and is executing them by the thousands and tens of thousands in copper, brass, and chromium plate. Such articles have the advantage of color contrast in red, yellow and white, but this is not necessary — witness the rapid sale last Christmas of articles made of aluminum by Wendell August Forge, hand made, remarkably finely wrought, yet reasonably priced. Chase and August creations stand out amongst competitors like Pike's Peak above the prairies.

A final tip to the stainless steel people: What the country really needs is a good dollar bridge prize!

Springs & Shock Absorbers

EVERYONE remembers the fanfare which introduced independent springing for front wheels on some makes of automobiles last year. Less is said this year about the return of the lower priced cars (1935 models) to elliptic springs on the front ends, leaving coil springs and independent springing to the more opulent buyer who can afford it as extra equipment, or drives one of the more expensive automobiles.

In a way the many-leaved flexible springs of the elliptic types are a reversion to ideas held in the days of carriages and phaetons (horse-drawn, we mean). As the automobile developed, springs at the front end became stiffer and stiffer. Certain engineering considerations as to sidewise stability, the steering geometry, soft tires, and increasing stresses from four-wheel brakes might be advanced as excuses for stiffer and stiffer springs, but probably one prime reason for the change was cost. It is considerably cheaper to build a spring with five, six, or seven leaves than it is with ten, eleven, or twelve. Economy also substituted square ends on each leaf, instead of the tapering sections indicated by correct design.

The net result was a vast increase in stiffness in the springs, and an associated development of the shock absorber. Probably the shock absorber would have been demanded anyway, but it is strange that it has taken all these years and a costly excursion into coiled springs to discover that the passengers in most automobiles are riding not on springs, but on shock absorbers, and that a little extra money spent on a better spring would avoid a larger expenditure on shock absorbers and give a smoother ride.

Hence we find one of the leading makers

putting a very flexible spring of the elliptic type on the front end of the car. It contains 11 leaves, each 0.175 or 0.155 in. thick, in place of six or seven leaves 0.200 or even 0.250 in. thick, which was common practice only two years ago. It is more flexible — that is, it deflects further after a given bump than the older ones, and the maximum stresses in tension and compression at the surfaces of the leaves (acting as modified cantilever beams) are in proportion to the deflection and inversely as the thickness. Hence such thin, flexible leaves must have higher endurance limits, and for this service the new carbon-molybdenum steel used in Dodge springs is manufactured and heat treated to an elastic limit of 200,000 psi. as compared to 120,000 psi. usually achieved in the conventional silico-manganese spring steel.

Excellent conditions at the surface are necessary in all springs in important service. Scale pits, decarburized surface, and other defects are potential (often actual) germs of fatigue failure. Hence the new material is rolled under close control to deliver a bar with smooth surface carrying the thinnest possible scale. Obviously springs made from them should be hardened in atmospheres controlled so that this scale should neither be increased nor reduced to a spongy layer of carbon-free iron. So we find a battery of long furnaces with controlled atmosphere in a spring plant — in itself a fact quite unique.

Long, deliberate heatings are of great value in another way — namely, fitting. Leaves come from the cambering machine true to shape, not warped. They therefore fit against one another smoothly, and transmit pressure from leaf to leaf rather more uniformly than other bars somewhat marred by scale pits. One difficulty with the old stiff springs was that the pressure between spring leaves varied greatly, and metal-to-metal contact could not long be avoided; hence the ever-present spring squeaks.

It is beyond the scope of this editorial note to discuss the vibrational period and dampening of the new spring designs. Suffice it to say that one virtue of independent springing on 1934 cars was to slow down the period of oscillation of the stiff front springs. Vibration rates decrease with the flexibility (to be accurate, the time of oscillation is proportional to the square root of the static deflection under a given load). Hence flexible springs are a move in the right direction toward slower rate and more comfort.

Furthermore, it may be mentioned that a shock absorber should be primarily a device for dampening these vibrations quickly. Dampeners act by converting the work absorbed by the spring into frictional heat. A multi-leaved spring, well fitted, is able to absorb much more of this work in interleaf friction than a stiff spring with fewer leaves. Hence it contains in itself a better mechanism for dampening the vibrations after hitting a bump, and thus takes a fair proportion of this work off the "shock absorbers."

Serving Diverse Interests

THE Pittsburgh, Chicago, Cleveland, and Detroit Chapters of the American Society for Metals have reached that size, in point of numbers, which the trustees of the national society anticipated several years ago — namely, where one line of activity is not sufficient to cover the interests of the entire membership. The case of the national society was taken care of by adding to the fundamental TRANSACTIONS and the practitioner's NATIONAL METALS HANDBOOK a new publication, METAL PROGRESS, for the man in production interested in metals yet not too well versed in metallurgical science.

To meet this same problem, Detroit Chapter's executive committee, over a year ago, decided to hold simultaneous meetings. On regular meeting night the group divides after supper; usually one speaker will consider some problem about iron and steel; the other talks about a non-ferrous metal or application. In Pittsburgh an even larger subdivision has taken place, requiring more frequent meetings, one of which will be advertised as of the highly technical type, another frankly is organized to be interesting to the steel worker, and still another is of general interest (the regular monthly meeting of the Chapter).

Cleveland Chapter proposes to handle the situation in another way. Its usual program consists of regular monthly meetings, which are intended to consider current metallurgical problems of most interest (either ferrous or non-ferrous, practical or theoretical) and a pair of lecture courses, one in the fall, one in the spring, on subjects receiving the most votes from the members. In addition to this, it is now intended to organize more informal discussions on specific problems, known to be interesting to relatively few members, but nevertheless extremely important from their point of view. Each of these may consist of only one or two meetings, where more smoking than orating will occur, under a chairman who will keep the discussion in the intended

channels — a conference or colloquium, as our English cousins would have it.

In Pittsburgh the technico-scientific meetings on the regular schedule are held in conjunction with the "Science of Metals Club," an informal group of high-powered scientists — well, high powered enough to take an integral sign or leave it. (There seems to be a goodly number of these men now concentrated in the Pittsburgh region.) It is related that at their very first meeting, a man attempted to give them a lecture on some subject he was not thoroughly familiar with, and it was like throwing a bone to hungry wolves. The meeting was so enjoyed by all, including the speaker, a man of humor, that ever since it has been the practice to interrupt with pertinent questions at any time, rather than saving discussion to the end, when it is usually found to have quietly expired meanwhile.

It is this vivacious plan that is in prospect for the Cleveland conferences. It is a plan that can be applied to many dull technical sessions.

Cooperative Studies Are Completed

ON FEB. 8 was held the eighth meeting of the Metallurgical Advisory Board to Carnegie Institute of Technology. These meetings have become one of the important technical events of the year; in this one there was an undercurrent of regret, since the study of the physical chemistry of steel making, started in 1926 as a five-year program, has been completed and the staff disbanded.

Notable changes have taken place in the steel industry in the intervening years. Possibly the greatest of these was described recently by a prominent steel maker as a "new willingness to study and understand technical problems; a new resolve to cooperate throughout the many phases of production, processing, fabricating, and service; a new search for the cause of each effect."

It is no faint praise to say that the organization, financing, and prosecution of these studies (directed by Charles H. Herty, Jr.) into the physical chemistry of steel making — that is, slag control and deoxidation practice — is one most tangible evidence that the steel master's remarks were not merely so many words, lip service to an ideal.

* * *

Those who are interested may refer to a critical review of these studies in an editorial in METAL PROGRESS for December, 1932.

Five Billions in Coppers

THOSE who like to invent comparisons which are supposed to enable one to comprehend the infinitely large or the infinitely small (like the age of the earth or the size of an atom) have been busy on the $4,880,000,000 asked by the President to relieve suffering by unemployed and to make them again consumers — that is, to improve business.

Some have figured how long a line of dollar bills it would amount to, and it reaches from here to there. Others — probably believers in hard money — have figured that it equals about 500 billion pennies, and this would require 1,550,000 tons of copper at the rate of 150 pennies per lb., and a 95% copper alloy (get out the old slide rule and check it up, only be sure of the decimal point!), and this would absorb the entire production of American copper mines for two years, straining to capacity.

Such a simile probably does not mean much to anyone who has not traveled extensively in the West and therefore has no idea of the preponderating importance of copper to all the inhabitants of the Rocky Mountain States. It's a lot of copper — it's a lot of money!

But others, more stout hearted, can also figure that it's a matter of $35 for each of the 141,574,000 men, women, and children the Census Bureau says we now have. On that basis it doesn't look so alarming, for we doubtless can stand it. As a matter of fact $35 is little more than each citizen is contributing, in general taxes, penny by penny, which goes to various city and county governments, most of which ought to be starved out of existence.

At least when the $4,880,000,000 is spent, we'll have some grade crossing eliminations, some roads, some forests, some slum clearance, some power plants to show for it. Undoubtedly, also, several million unfortunate citizens will have a better outlook on life, and probably the number will include some pessimistic business men.

Personal Note . .

ALL ASMembers will join in congratulating two of the Society's trustees who have recently had gratifying promotions. Edgar C. Bain has become Assistant to Vice-President, U. S. Steel Corporation, in charge of metallurgy and research. Walter Mathesius has been made General Superintendent of the huge South Chicago plant of Illinois Steel Co.

Become a trustee and go up in the world!

Some of the Alloys That Age Harden

By PAUL D. MERICA
Assistant to the President
International Nickel Co.
New York City

IN AN ARTICLE PUBLISHED IN METAL PROGRESS in January, some of the generalities concerning age hardening were discussed. In this one I propose to introduce some of the interesting individual members of this family of alloys. Although preserving a family resemblance to each other, they do also display some curious and often useful differences in behavior.

Duralumin

With traditional respect one is almost obligated to admit duralumin first from the waiting line, although my comment will be brief, since this alloy has had a good deal of public recognition and we all know a great deal about it already.

Duralumin, together with other alloys of the same type, has been responsible for very constructive developments in the aircraft, the railway car and the motor-truck industry where light structures are economical and may even be required. Just recently several high speed trains of new design have been built with it. In such structures it has been demonstrated that it is possible by its use to reduce weight 25 to 50% under that of steel construction, with obvious attendant savings in power consumption.

The use of duralumin in dirigible and aircraft construction is well known. Less known, but equally important, is its use for light-weight floor systems in long bridges, or bridges which are hardly able to carry increasing traffic.

The use of these light, hardenable alloys has, up to this time, probably greatly exceeded in tonnage that of all other such alloys combined. In consequence, more accurate information is available concerning them than about the others. Duralumin therefore serves us as a guide, both from the metallurgical and engineering standpoint, in developing other age hardening alloys.

Although its characteristics are conventional enough, it is far from being one of the simplest of the age hardening alloys, and in fact the original duralumin of Wilm has proven to be twins! Metallurgists have taken it apart and found two perfectly good alloys in it, each of which develops about the same mechanical properties as the original duralumin, but which have very useful differences now being exploited. Duralumin contains about 4% of copper in addition to small percentages of magnesium and silicon probably combined as magnesium silicide, Mg_2Si. Both constituents are quite capable alone of conferring hardening power upon aluminum, and are today separately used. In fact, the specialization of duralumin has proceeded even further, and a whole series of alloys, both for castings and for forgings and sheet, has been developed and is in commercial use, based on one or the other of these two active hardening "components" of duralumin. Each of the special alloys has certain special advantages — usually from the standpoint of fabrication.

One of the many interesting features of the age hardening of duralumin at ordinary temperatures is that it occurs with less impairment of ductility than is usual among such alloys. In fact, the elongation and reduction of area as determined in the tensile test are hardly affected during an aging treatment which increases the hardness very substantially. This is most unusual behavior and indeed unique, as far as I know, among age hardening alloys. Besides being of very real practical value, this behavior has important theoretical implications and suggests that the internal distortion in the duralumin

lattice which is responsible for hardening must be of a milder and less harsh character than that induced in other alloys.

Another interesting point is that the age hardening of the 5% copper-aluminum alloy, one of the duralumin twins, may be most profoundly affected by the presence of small amounts of other metals. When the alloy is quite pure and free from iron, it hardens quite appreciably at room temperatures. When even small amounts of iron are present, less than 1.00%, room temperature hardening is inhibited almost completely. If, now, ½% or less of magnesium is added to the iron-bearing alloy, room temperature age hardening is restored.

We are confronted here with "accelerators" and "retardants" of aging — and numerous other cases have been established of similar behavior. Now in this case (and in many others) this accelerating or retarding effect of addition metals is not due to any effect of these elements upon agents. The explanation indeed is not finally known, but it must lie deeper. In some cases it may be due to surface reactions of the dispersed particles, as Seljesater has suggested, but in the case of duralumin it is probably due to the effect of the added elements in influencing the course of atomic diffusion, and thus determining the size and distribution of the disperse particles which cause the hardening.

There are many other equally intriguing and bizarre features of the age hardening process in duralumin — characteristics which, as we understand them better, will undoubtedly reveal to us more and more of its inner mechanism. I must, however, reluctantly close my comment on this classic alloy and pass on to some others which, although newer, may ultimately prove equally valuable and interesting.

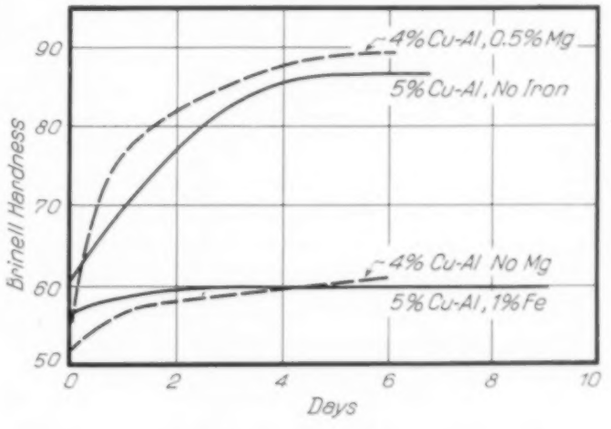
Hardenable Gold Alloys

Very few of us occupy ourselves much with the alloys of gold and of the platinum metals — nor indeed ever get much opportunity to lay our hands on any of their components! Yet there has been developed in recent years a pretty detailed technology of these alloys, both in the jewelry and in the dental field. Strangely enough, age hardening was probably known and practiced by the dentists, even before the discovery of duralumin in 1911. In those days we had an astonishing ability to keep our metallurgical information in separate and closed compartments!

Those of you who are unfortunate enough to own some of the finer examples of the dentist's art, will agree that he asks a great deal of his materials. They must be capable of fabrication into delicate structures of bridges and dentures; they must be resistant to tarnish and corrosion; and parts of them at least must have quite superior mechanical properties — in particular, high elastic limits. It is not surprising that investigators, happening upon the phenomenon of age hardening in dental alloys, early turned it to good account and have developed it into a principal asset of their art.

The properties which are obtained in some of the modern dental golds are quite surprising, and are rendered possible by the addition of from 10 to 15% of platinum or palladium. Fourteen to 16-karat golds of this description will give tensile strengths as high as 150,000 psi., together with elongations on wire of 10%, and proportional limits between 80,000 and 100,000 psi. One is hardly prepared for properties of this character, built on the comparatively soft metals gold and silver!

The mechanism of hardening in these alloys is very far from clear. It is sure, however, that



Curves for Hardness After Aging at Room Temperature of Aluminum-Copper Alloys (Fraenkel). Iron "restricts" hardening of 5% copper alloy, and magnesium "extends" hardening of 4% copper alloy

it is not of the simple "duralumin" type, in spite of the fact that the effects of heat treatment are similar. Hardening evidently depends upon the formation of the compounds Au-Cu, Pd-Cu, or Pt-Cu, whose molecular formulas may be debatable, but which are stable at low temperatures and unstable at higher ones.

The alloy containing 50 atomic per cent gold

and 50 copper, for example, exists at temperatures above 750° F. as a face-centered cubic lattice with the gold and the copper atoms arranged in a random manner on the points of the lattice. In this condition the alloy is soft, and it may be preserved at ordinary temperatures in this condition by quenching from above 750° F. Upon slow cooling through that transformation temperature, however, the lattice changes to a tetragonal one (also face-centered) and the atoms station themselves symmetrically to form a compound Au-Cu. This compound is also soft. But when the transformation at 750° F. is suppressed by quenching and the alloy is allowed to undergo partial transformation by tempering at a lower temperature — say 400° F. — the hardness is increased very considerably.

The compounds Pd-Cu and Pt-Cu behave quite similarly.

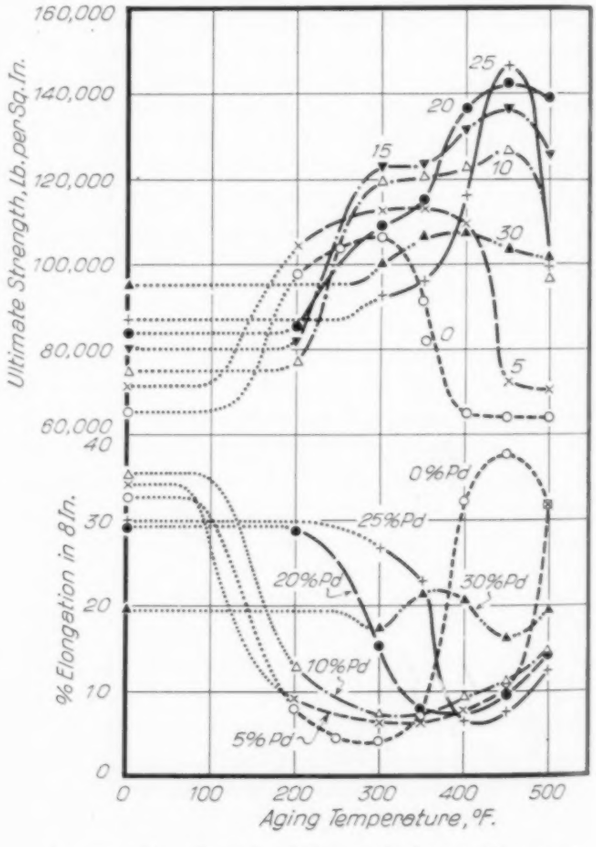
When the four or five metals — gold, silver, copper, platinum, and palladium — are all present in an alloy, the hardening mechanism is much more complex, and is not yet well understood, but there is sufficient evidence to indicate that it is related to the formation of one or more of these compounds during tempering, probably in distorted lattice form. As a matter of fact, Wise has shown that the aging-temperature curves of the gold-silver-copper-palladium alloys exhibit two distinct maxima of hardness; one at about 575° F. and one at about 850° F., the former being due probably to the precipitation of Au-Cu, and the latter to that of Pd-Cu. First the one compound forms, giving rise to moderate hardness, and at high temperatures the other, increasing the hardness still further. Seldom do we find two hardening constituents cooperating in this manner in the same alloy.

Aluminum-Copper-Nickel Alloys

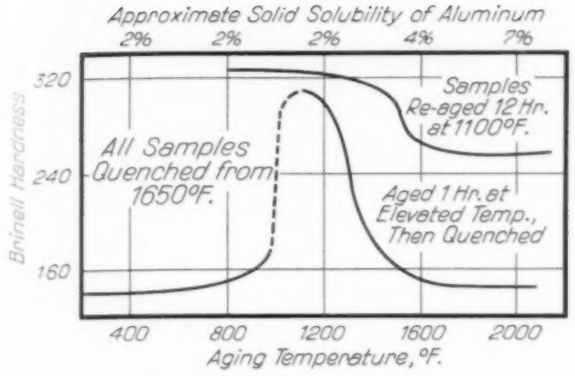
The alloys of aluminum, copper, and nickel form an interesting series of age hardening alloys. Copper dissolves about 10% of aluminum in solid solution, and nickel about 15% of aluminum; neither of these alloys is age hardenable, however, due to the fact that there is little change of solubility of aluminum with temperature in either metal. The copper-nickel alloys also are not themselves hardenable upon aging.

However, the solubility of aluminum in the copper-nickel alloys at ordinary temperatures is reduced to values ranging from 0.5% to 3%, and its solubility-temperature curve is so altered as to permit age hardening. The useful range of these alloys contains from 10 to 80% of nickel and from 0.5 to 5% of aluminum, and the actual hardening constituent is probably a solid solution of Cu_3Al and Ni-Al.

These alloys, as Dr. Mudge has shown, display heat treating characteristics which are a bit unconventional, and it is partly for this reason that I am mentioning them. Apparently they do not over-age as do the more orthodox alloys. Thus, an alloy containing about 68% nickel, 28% copper, and 4% aluminum is soft after annealing and quenching from 1500° F., and is hardened by a stay at 1100° F., the optimum tempering temperature. If tempered above that temperature, the alloy indeed softens, but because the hardening constituent goes back into solution, and not because the particles coalesce ("over-aging" in the usual sense). There is apparently no temperature at which the hardening precipitate is itself stable and insoluble, and



Curves Showing the Effect of Aging Temperature on Gold-Silver-Copper Alloys Containing Various Atomic Per Cent of Palladium, According to Wise. Maximum hardness when aged at 300° C. (575° F.) for the palladium-free alloy, and at 450° C. (850° F.) for the 25% palladium alloy indicates two distinct agencies at work



Monel Metal (Copper-Nickel Alloy) With Aluminum Cannot Be "Over-Aged" (After Mudge). Lower curve shows conditions after quenching from 1650° F., tempering one hour at indicated temperature, and cooling quickly. Upper curve is for same samples after additional tempering (high temperature aging) for 12 hr. at 1100° F.

at which it will coalesce into unduly coarse particles and thereby soften the alloy.

In consequence, these alloys may be hardened very satisfactorily by slow cooling from the annealing or "solution" treatment. Indeed, the best properties of these alloys are actually secured by fairly slow cooling from about 1500° F., followed by tempering at 1100° F. In this condition there may readily be obtained a combination of properties such as the following:

Proportional limit	over 100,000 psi.
Tensile strength	over 150,000 psi.
Elongation	over 15%
Reduction of area	over 30%

These figures remind one of the values obtainable in good grades of alloy steels. Attention may be called to the excellent ductility, associated with high tensile strength and proportional limit. The aluminum-copper-nickel alloys share with duralumin the distinction of hardening without undue loss of ductility; they are not, however, fully equal to duralumin in this respect.

A material of this type has certain obvious advantages. It can be softened and hardened by the conventional heat treatments if so desired, but if, on the other hand, drastic heat treatment is for any reason undesirable, its enhanced properties can be secured through simple slow cooling. It is thus more flexible in its adaptation to fabrication than the simpler type of age hardening alloy, which requires drastic cooling or quenching. It is not difficult, for example, in consequence of the sluggish nature of the hardening reaction, to secure excellent physical properties in heavy sections, and some of the current uses of one composition of this series involve the exploitation of this useful characteristic.

Although the commercial development of the aluminum-copper-nickel alloys has been hampered somewhat by difficulty in hot working them within certain temperature ranges, this situation has been lately improved. Some of these alloys have been and are currently used for certain applications requiring a high degree of corrosion resistance plus high hardness or strength.

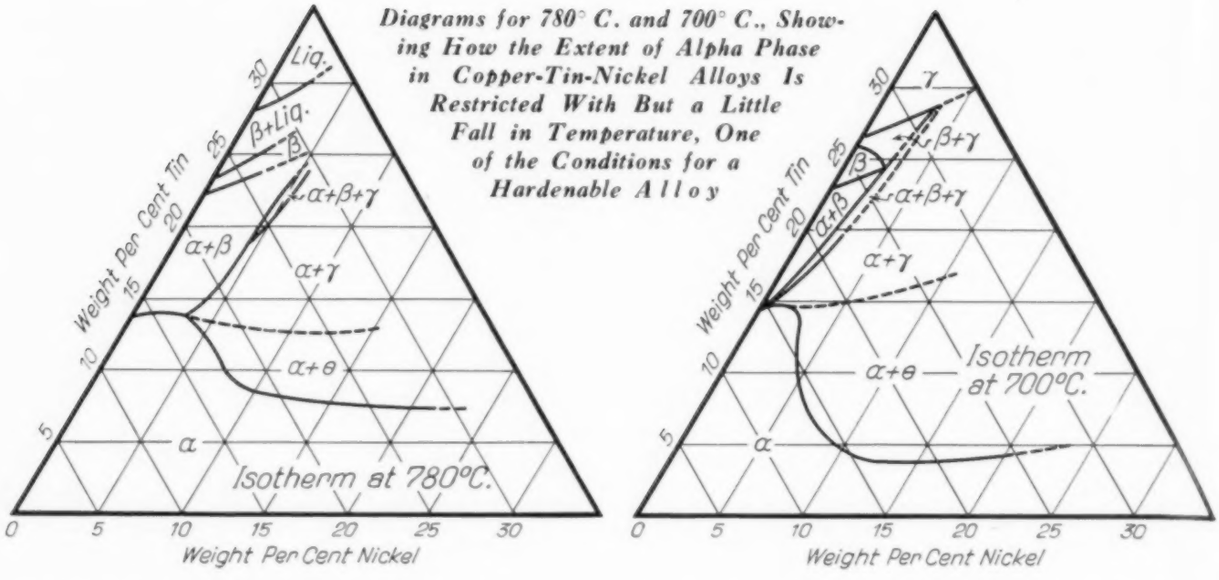
Age Hardening Copper Alloys

The metal copper is a natural target for any and all new metallurgical tricks, and it is not therefore surprising that it should have been subject to pretty heavy attack on the part of age hardening inventors. The results have been interesting and useful.

Perhaps the most striking one has been the pretty widely advertised beryllium bronze, containing about 2.5% of beryllium. This material, which is readily rolled either when hot or cold, is fairly soft and ductile when annealed, with a tensile strength of 55,000 psi. and an elongation of 55%. When quenched and aged it is very substantially hardened and strengthened and can boast of tensile strengths over 150,000 psi. together with most respectable elastic limits — over 80,000 psi. When cold worked and aged, the properties are still higher. Ductility after such treatments, as evidenced by an elongation of about 1.5%, is unfortunately low, but it is entirely adequate for many purposes, and in particular for that for which the material is principally used — namely, for springs.

One of the most interesting features of this alloy is that, unlike many age hardening alloys, it appears to have its fatigue properties enhanced. Unfortunately, those heat treatments that increase substantially the tensile strengths of duralumin and several other age hardening alloys often raise their endurance limits but modestly. It is one of the few disappointing features of such alloys, and is a disability which, as far as I know, has not yet been generally overcome. But for some reason, still wholly obscure, beryllium bronze shines very brightly in this respect, and Dr. Gillett reports fatigue limits in the neighborhood of 100,000 psi. for the properly heat treated material.

It is for this reason, of course, that it has been greeted so enthusiastically by spring makers and users, and it is to be hoped also that its



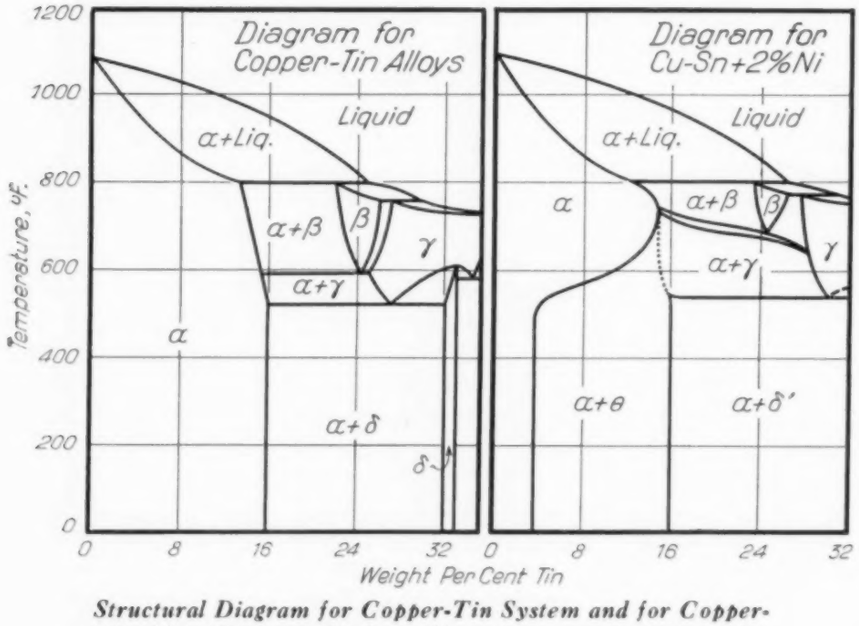
Diagrams for 780° C. and 700° C., Showing How the Extent of Alpha Phase in Copper-Tin-Nickel Alloys Is Restricted With But a Little Fall in Temperature, One of the Conditions for a Hardenable Alloy

unique behavior in fatigue may ultimately serve to show us how to correct the corresponding fault in other hardenable alloys.

Incidentally, beryllium seems to hold the championship among precipitation hardening agents. It works not only in copper but in nickel, in iron, and in austenitic steels as well and does a really good job of it in all. The metal is perhaps a bit expensive, but if you need an efficient hardener for your particular alloy problem, don't overlook beryllium!

There are, however, other useful and effective copper hardeners. One of them is being used currently in a product of one of the brass mills called "Tempaloy." The hardener is a compound, nickel silicide, and the alloy contains about 4% nickel and about 1% of silicon. This variety of hardenable copper is readily worked hot and cold, and develops strengths in the neighborhood of 120,000 psi., together with quite good values of yield point, but with somewhat low values of ductility — 6% and 12% for elongation and reduction of area respectively.

Other hardeners such as aluminum, nickel, nickel-tin, and chromium-silicon will also harden copper very effectively. One of these leads me, indeed, directly to my next topic.



Structural Diagram for Copper-Tin System and for Copper-Tin Alloy With 2% Nickel. Note the great change which a little nickel produces in the boundary of the alpha phase

Nickel Bronzes

It occurs to me that in reviewing hitherto some of the useful age hardenable alloys, I have placed undue emphasis upon wrought alloys — although I did point out that aluminum alloys as well as those of the precious metals may be and are temper hardened in the cast state. May I then, in order to correct this impression, call your attention to a series of alloys which may prove to be useful chiefly in the

(Cont. on page 74)

Heat Treatment of Spring Leaves

By W. C. OWEN
Factory Manager
Detroit Steel Products Co.

FOR 31 years Detroit Steel Products Co. has manufactured leaf springs for standard equipment on automobiles, trucks, cabs, buses and trailers. This firm also makes "Fenestra" steel sash and doors for the building industry. In 1929 it was decided to segregate these two dissimilar lines, and accordingly a separate plant for the manufacture of springs was built.

The Original Equipment

In the new spring plant, the machinery was arranged for straight-line production, beginning with the raw material, through all preliminary operations, then to heat treating furnaces, and finally to the assembly conveyors.

Fuel oil was used throughout, for heating ends and centers of spring leaves (for tapering, curling of eyes and embossing), and for hardening, forming and annealing the leaves prior to assembly. The hardening furnaces, moved from the old factory, were then 10 years old. Furnace floors were slotted for conveyors, which were of the walking beam type.

A very large quantity of spring steel has been handled with this original equipment. Practically all of it has been silico-manganese steel, S.A.E. 9250 or 9260.

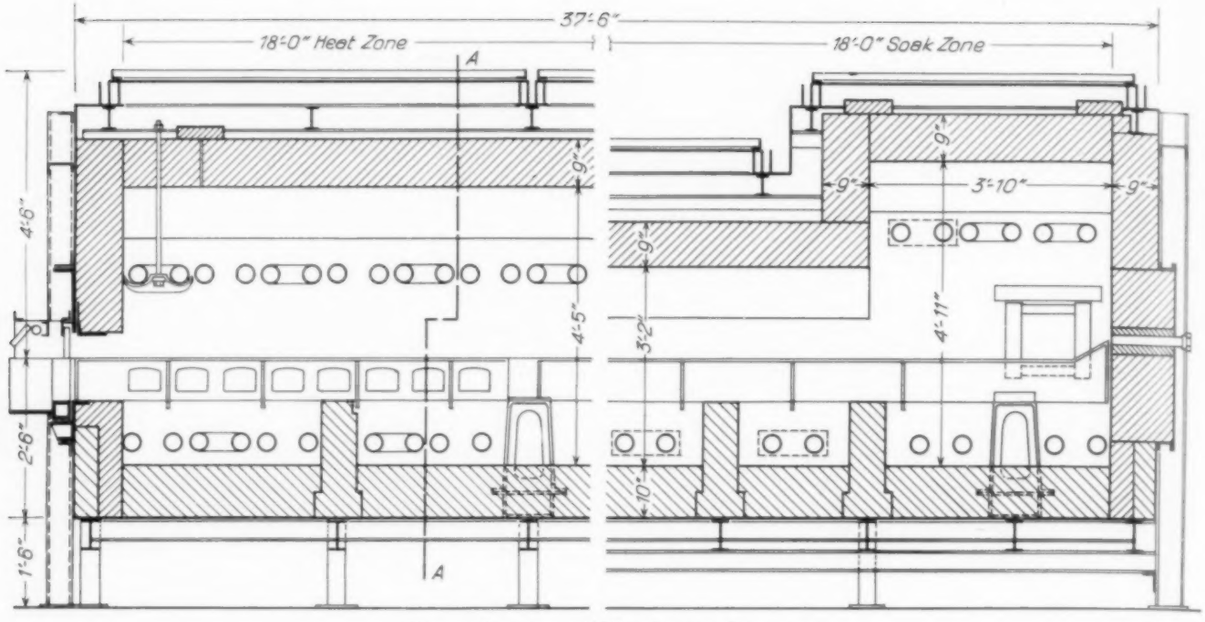
Due to the fact that the leaves were heated from the top surface only, the old furnaces being over-fired, the speed at which the work could be put through was seriously reduced. Another objection, from the modern viewpoint, was that the fuel oil control system was slow to respond to temperature changes, causing as much as 40° F. variations in temperature from the control point. And while the silico-manganese steel is relatively insensitive to this condition (a wide quenching range being one of its prime advantages), such large swings were suspicious, and were certain, eventually, to lead to trouble, as inspection became more stringent. A final objection was the fact that these furnaces did not lend themselves to atmospheric control.

The New Hardening Furnaces

It became apparent, when we were asked to build springs under furnace conditions that would add absolutely nothing to the original mill scale, that entirely new furnace equipment for hardening and drawing would have to be installed. This has now been done; the new equipment, built by the Surface Combustion Corp., represents a fine achievement and warrants a rather full description.

In the design of the new furnaces, several fundamentals had to be kept foremost in mind. The capacity must be large, even though the customer might specify an unusually long "soak" for the springs at the hardening temperature. This requirement means a long furnace, and a fool-proof conveying mechanism which can be speeded up or slowed down through a wide range. The walking beam type of conveyor had proven itself, and it had the added advantage that it could be driven from one end, and would require no openings in the sidewalls, discharge-end wall or bottom. (Speed variations are had through an 8 to 1 range, by adjustments which change the forward stroke between 6-in. and 12-in. limits, and a time clock which varies the intervals between strokes as much as 4 to 1.)

Since the furnace was to have atmospheric control, it meant that the products of fuel com-



Cross Section of Hardening Furnace

bustion, required to generate the heat, must be entirely separated from the work in the furnace. The furnace was too big to think of an interior muffle or tube 46 ft. long by 6½ ft. wide by 1½ ft. high inside, to enclose the work. But, as an alternative, the products of flame combustion could be carried in a number of tubes, bent like hairpins, placed above and below the hearth.

For quick and efficient heating, the work should be heated both from above and from below — that meant that the conveyor hearth must be skeletonized.

Next the furnace should be tight, well insulated against radiation, but especially proof against leakage of the prepared atmosphere, which not only would be wasteful but actually dangerous, as it contains a large proportion of toxic gases.

Lastly the temperature must be controlled precisely, and its distribution must be uniform within 5° F. (plus or minus) through the soaking zone. Many of the details can be seen in the mechanical drawing and from the photograph of the furnace in operation (page 54).

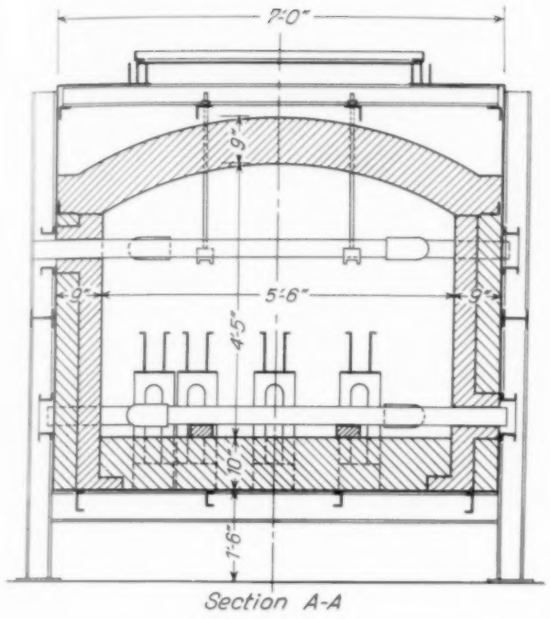
Radiant Tube Heaters

In actual construction, perhaps the most interesting feature of the hardening furnaces is the "radiant tube" heaters, shaped like hairpins. These are 3 in. inside diameter, with ¼ in. wall thickness, and are made of cast chromium-nickel-iron; they are joined at the inner end by a return bend of the same alloy. In all, 56 heaters are used in the 38-ft. furnace (and 59 in a 46-ft. furnace) — some placed above the work, carried on hangers, and some are below the work, supported by pedestals between conveyor piers. In the heating zone of the 38-ft. furnace, 28 heaters are located above the work and 16 below. Twelve are below the hearth in the soaking zone.

Most of these hairpin tubes extend nearly to the opposite wall; but near the entrance, in order to develop the maximum amount of heat where the cold charge enters, shorter "hairpins" extend from one wall half way across the furnace to meet others which extend from the opposite wall.

At the open end of each of these U-tubes, outside the furnace, a gas burner is centered. A lazy flame extends down the axis of the tube, gradually combining with the air drawn in or aspirated around the burner through the open end of the tube. This is true diffusion combustion of streams of gas and air, moving in parallel, non-turbulent flow. (The principles have been thoroughly explained by W. M. Hepburn, in METAL PROGRESS for September, 1932.) Such a flame can be drawn out to great lengths, and the turbulence introduced at the U-bend is therefore of advantage in mixing the unburned gases with the remaining air, so combustion will be completed before the outlet is reached.

At the exit end of each tube is a short chimney. Just above its connection with the radiant tube, this chimney is narrowed into a venturi throat. At its bottom is a small jet of



Section A-A

compressed air at 1 lb. This device acts as an eductor for the burned gases, and gives the necessary gentle suction for drawing combustion air into the entrance end of the radiant tube, around the gas flame. The chimney is also a ready means of controlling the distribution of gas from the header into each of the individual heaters. These adjustments are only necessary when the furnace is originally started.

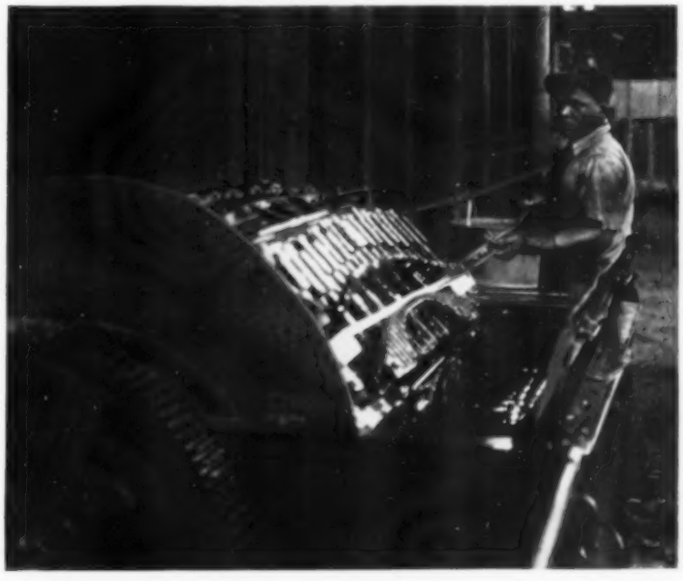
Obviously the important point in the utilization of the radiant tube heater is in establishing a temperature distribution throughout the length of the tube which will give uniform heat within the furnace, and which will permit low outlet temperature of the gases. In connection with the turbulence which the U-bend of the heater tubes creates, the engineers for Surface Combustion Corp. have found that on some long, straight tubes, devices for setting up a certain amount of turbulence are purposely incorporated at some point midway.

Temperature distribution of U-shaped tubes has been very carefully determined in the laboratory, under various conditions of operation. In our furnaces these figures are about as follows, for a flame which produces temperatures of 1600° F. just inside the furnace sidewall: 12 in. inside, 1640° F.; 24 in. inside 1690° F.; 30 in. inside, 1700° F.; 36 in. inside, 1700° F.; 42 in. inside, 1690° F.; 54 in. inside, 1640° F.; 68 in. inside, 1590° F. These are indeed small variations for a fuel-fired source of energy; and when it is remembered that these represent temperatures of a radiator about 14 in. from the work, the uniformity of heat distribution at the level of the work is explainable. To one who has worked for many years with oil-fired furnaces, the temperature uniformity at the hearth of the new furnaces is indeed a revelation.

Diffusion combustion, plus the educator, also permits us to burn far more gas in a 3-in. tube than could be burned by the conventional nozzle-mixing burners delivering air and gas under pressure. For example, the conventional equipment can burn around 180 cu.ft. of city gas per hr. in a tube 3 in. diameter. Any attempt to go above this amount begins to register an excessive resistance, and finally reaches a point where so much backfiring occurs as to be practically inoperative. With our arrangement we are running with ease around 400 cu.ft. of city gas in the same sized tube. As these tubes radiate at a tremendously high rate, one can readily see the advantage of being able to put in a supply of heat which permits the tube to be maintained for long periods at the high radiating temperatures. Such high rate of heat productions, without sacrificing any uniformity, is very important from the standpoint of a furnace with high capacity of output, for obviously the cold metal constantly entering must encounter a reservoir of heat sufficient to bring it up to correct temperature in short order.

In operation, the spring leaves are at hardening temperature by the time they have progressed

Dies of "DSP" Forming Machine About to Close on Hot Spring Leaf. A series of cam operated levers clamp the bar against camber block and the drum rotates, quenching the bar in oil



approximately one-third the length of the furnace. Two-thirds, therefore, are soaking — now thought by many metallurgists to be a prime advantage. Temperature is controlled at three zones — at the charging end, in the intermediate soaking zone, and in the final soaking zone. An average thermocouple record of the first point shows slow fluctuations of about 25° F. (plus or minus) of the control point. The other zones are easily held to 5° F. plus or minus. Some specifications call for a soak of as much as 25 min. at heat before quenching — this again is a reason for a long furnace of great capacity.

In production, the spring leaves arrive at the charging table at the entrance end of the hardening furnace, cut to length, punched and with eyes of main leaves curled. As the leaves are fed into the furnace on the walking beam conveyor, they are laid flat, side by side, in correct order for assembly, so that all the leaves of a complete spring travel through together and in the proper rotation. Observe, from the cross-section on page 53, that the walking beam conveyors at the left side are only 8 in. center to center, to carry the shortest leaves.

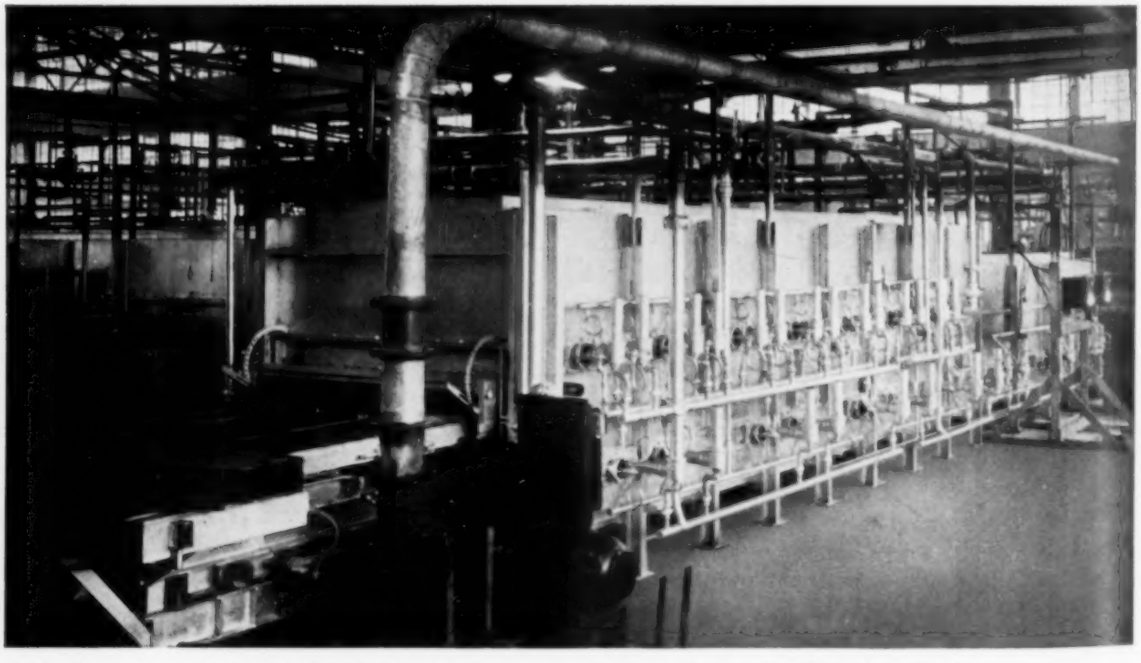
The automotive industry now demands spring leaves with little or no addition to the scale attached to the bars as received from the steel mill. This means the leaves must be hardened in a truly neutral atmosphere. It appears that this atmosphere is about the same for all the 50-point carbon spring steels at 1500° to 1600° F., the usual hardening temperatures, and should contain a high percentage of carbon monoxide and no free oxygen.

Neutral Atmosphere for Hardening

This atmosphere is quite easily formed in a so-called "DX Gas Generator" of Surface Combustion manufacture, which mixes city gas with a limited supply of air (about 60% of the quantity of air required for combustion), washes the mixture, dehydrates it and cools it, so that the gas, when prepared for distribution to the point of use in the hardening furnace, is oxygen-free, water-free, uniform and clean. These units, which are similar to the one illustrated in METAL PROGRESS, October issue, page 100, are quite compact and practically automatic.

To prevent the loss of our prepared gas at entrance and exit doors of furnace, some interesting air or gas "screens" have been installed at these points.

The furnace entrance door is a slot, furnace width and 6 in. high (maximum). A sheet steel portal extends out about 18 in.; across it, just under its ceiling, is a gas pipe perforated with a



Side Elevation of One of the Hardening Furnaces, Taken From the Charging End. Note row of burners, both above and below walking beam conveyor hearth. Each fires into U tube, and products of combustion vent through short stack at outlet

long line of small holes. This pipe is connected to the main gas supply, and a lazy flame burns downward, completely filling the portal, and effectually burning any of the toxic gases which may reach this point. A hinged apron can be lowered to narrow the entrance slot to the minimum, leaving the opening just high enough to clear the incoming work.

At the exit or discharge door — cut in the side wall, approximately 7x9 in. — a series of nozzles blows a blanket of low pressure air directly across the opening, catching any escaping gas, and carrying it into a small hood and thence out of the building.

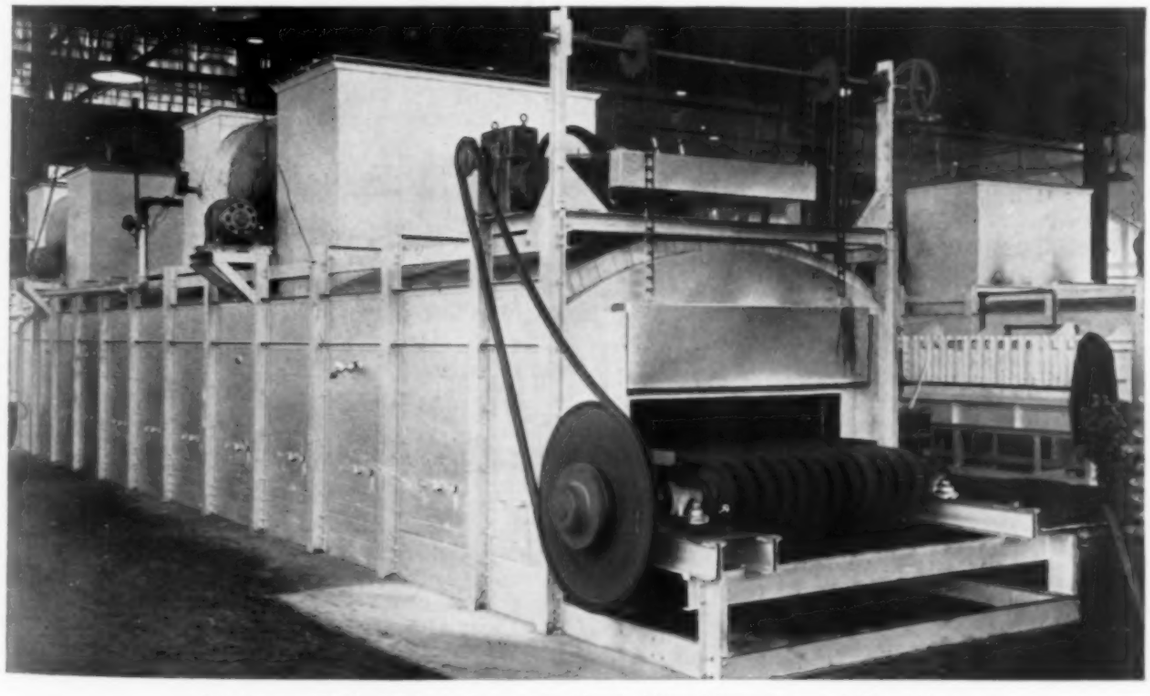
The "DSP" Forming Machine

From the hardening furnace the hot leaves pass to a "DSP" forming machine, so called because this fixture was designed and built in the shops of Detroit Steel Products Co. Essentially it consists of an octagonal drum with eight sets of forming dies, one set to each face. The drum is partially submerged in quenching oil, its three upper faces are exposed, and its five lower faces almost entirely immersed. After a hot plate is placed between the dies, the machine is tripped, and while the drum is revolving 45° the dies are automatically closed by cam-operated levers, forming the plate to correct curvature before it is plunged into the quenching oil. This machine is shown on page 53.

The New Draw Furnaces

As the spring leaves emerge from the quenching oil (by an elevating conveyor) they are grouped in sets, in correct order of assembly, and are placed edgewise on the conveyor which forms the bottom of the draw furnace. This conveyor is of a novel design, consisting of 12 endless chains, set side by side, and traveling over sprocket wheels at either end of the furnace. Short ears project from either side of each chain link in such a way that the whole interlaces and practically forms a wide link belt. The conveyor material is a high strength "Promal" iron, quite light in weight. Inside the furnace it slides over longitudinal supporting rails. (The general appearance at the discharge end is shown in the photograph, unfortunately taken while conveyor was operating, thus obscuring the details.)

The draw furnaces at Detroit Steel Products Co.'s spring plant have about the same cross sectional areas as the hardening furnaces, and were built to meet a specification to heat to drawing temperature (say 800 to 900° F.) in 20 min., and hold at temperature ± 5° F. *(Cont. on page 64)*



Discharge End of Draw Furnace Heated by Circulation of Hot Air. Note two air heating units, with fans, built above the furnace roof

Correspondence and Foreign Letters

BIRMINGHAM, ALA. — It would be well to remind those readers of Professor Portevin's interesting letter about the determination of the founding properties of alloys, in the January issue, that the Gray Iron Committee of the American Foundrymen's Association has been working along these lines for some time. We feel that we have a very accurate form of test for "castability," and one which can be used in anybody's foundry with a fair degree of reproducibility.

Difficult Tests for Founding Properties

As to the tests for shrinkage and other properties, the situation is far from satisfactory. The foundry section of the Bureau of Standards worked out a method for the determination of volume changes, but this requires a very high class organization for its successful manipulation, and it is hardly conceivable that any but the largest foundries could use the method. When we come to any available procedure in the foundry we are immediately up against the problem of small differences in the weight of large masses, or else the mass of the casting is so small that the shrinkage is not sufficiently pronounced. Of course, there is the German proposal which involves molding of strain grids, but anyone who has tried it has been impressed with the very great difficulty in making such a test perform "acording to Hoyle."

Technical men in the foundry industry would indeed be grateful to Professor Portevin if he would give us a test specimen for these shrinks in castings.

J. V. MACKENZIE

PILZEN, CZECHOSLOVAKIA — We have noted frequently that differences of opinion arise because, in spite of the recent progress in the metallography of steel, its terminology remains almost unchanged and therefore violates modern conceptions about the nature of some of the microstructures. We, in the Skoda Works, have therefore attempted to standardize terminology for hypo-eutectoid steels along the lines indicated in this letter.

First as to the term "troostite," which is commonly applied to two different structures of different origin. Troostite develops directly from austenite. Latest investigations in Europe verify the conclusions printed by Dr. Lucas in last month's issue, that troostite formed on cooling has a lamellar structure like pearlite; only a gradual difference in fineness and density of cementite lamellae exists between normal pearlite, "sorbite" and troostite appearing in the steel specimen as the rate of cooling is increased. It would therefore be more correct to use the single term, pearlite, to distinguish them. This was done, in fact, by E. C. Bain in the 1932 Campbell Memorial Lecture when he used the terms "coarse pearlite," "medium pearlite," and "fine pearlite."

Troostite Sorbite Pearlite

However, because the conditions at which the troostitic structure develops are sharply limited, and the grains have a characteristic shape, we believe it would be useful to retain the term troostite, but to confine it to those cases where very fine pearlite occurs with martensite or austenite. The term sorbite will be reserved solely for tempered martensite.

Adding these ideas to Dr. Bain's terminology gives the diagram shown above the micros. It indicates that the structures developing pri-

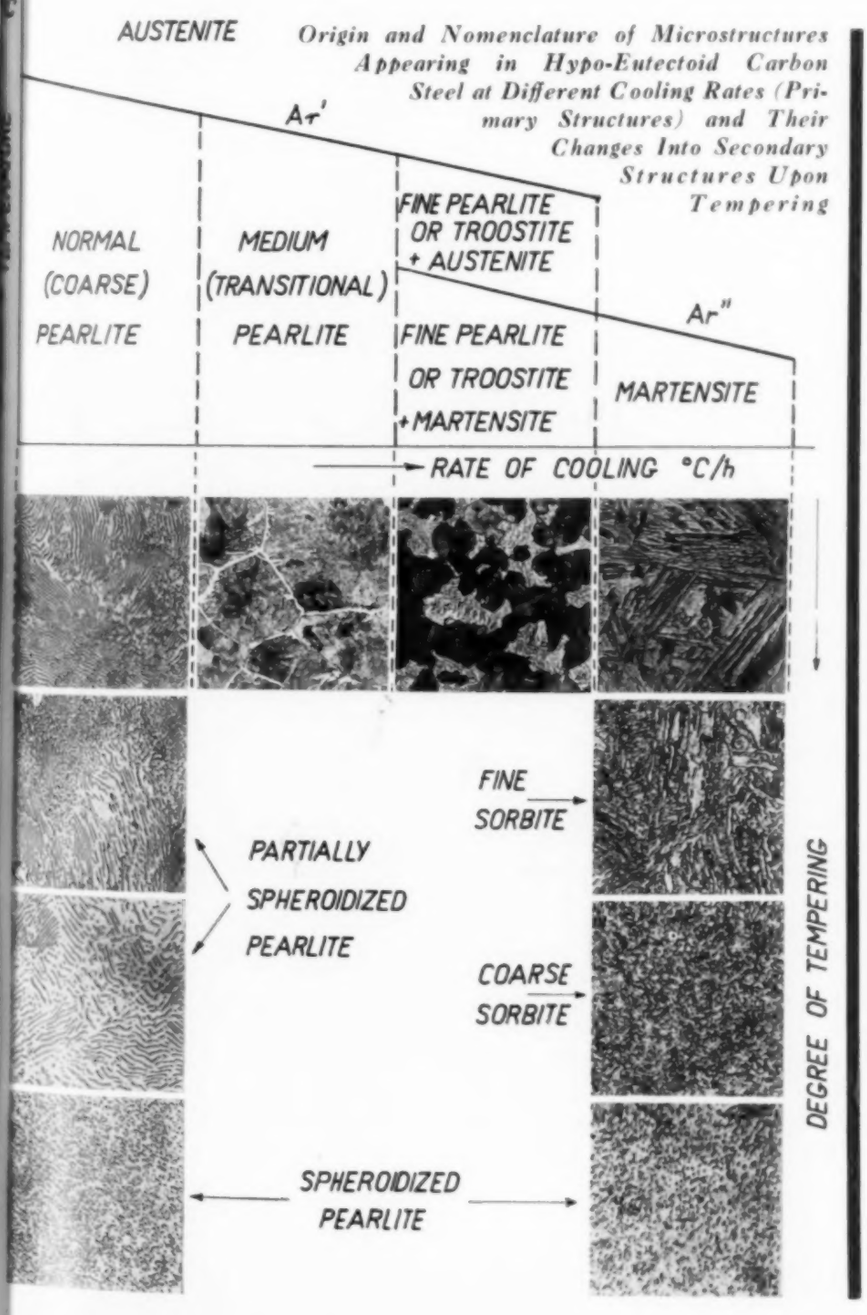
marily from the gamma phase are (*a*) pearlite, at the Ar_1 transformation, (*b*) medium pearlite at the Ar_1 or the Ar′ transformation, (*c*) fine pearlite or troostite at the Ar′ transformation, and (*d*) martensite at the Ar″ transformation. These may be called the *primary* structures.

So much for the primary structures appearing after cooling from above Ar_1. How about the *secondary* structures arising when any of them is tempered?

According to the latest investigations martensite is a supersaturated solution of carbon in α-iron (more precisely, iron atoms arranged on a tetragonal space lattice). Martensite is, therefore, characterized by an atomic dispersion of carbon in an iron lattice. Tempering develops first some so-called "troostite" — crystals of α-iron wherein are precipitated submicroscopic particles of cementite of greater dimensions than single molecules. Sorbite forms at a higher tempering temperature. In this structure separate particles of cementite can be observed at high magnifications. Finally, on long tempering, appears spheroidized pearlite.

The secondary structures developing from martensite when tempered therefore differ between themselves only in the fineness of cementite dispersion.

We would like to stress the fact that structures developing after tempering martensite (although they consist of α-iron and cementite) differ essentially from those structures developing directly from austenite upon cooling. This is shown by the two forms of the cementite particles. Spheroidization takes place on tempering; the particles of cementite acquire the shape of small globules. Structures of the lamellar type (characteristic of direct cooling) never appear in tempered martensite.



Origin and Nomenclature of Microstructures Appearing in Hypo-Eutectoid Carbon Steel at Different Cooling Rates (Primary Structures) and Their Changes Into Secondary Structures Upon Tempering

While the sorbitic structure differs from martensite quite considerably, one cannot draw a boundary between the so-called "temper troostite" and sorbite. Hardness and other properties vary continuously when martensite is tempered more and more thoroughly. While there are certain reasons to apply the term "troostite" to fine, primary pearlite, there is, in our opinion, no advantage in giving the same name to the initial stage of martensite decomposition on tempering. In fact, quite the contrary, for the sake of precision.

We suggest, therefore, that t e m p e r e d martensite should be called fine sorbite or coarse sorbite, according to its n a t u r e. Only coarsely coagulated sorbite should be called "spheroidized pearlite." The photomicrographs

illustrate the structures as discussed above. Vertical series of views illustrate the gradual change of primary structures to spheroidized pearlite. It should be understood, of course, that medium pearlite and fine pearlite (troostite) also change after sufficient tempering or annealing into spheroidized pearlite.

A coarse sorbitic structure can be naturally obtained by the decomposition of troostite, just as spheroidized pearlite can be obtained by annealing lamellar pearlite. This, however, does not bring about any change in our definition, that sorbite and spheroidized pearlite are secondary structures whereas martensite and lamellar pearlite (or troostite) are primary structures.

The above should apply to carbon steel, for standardization of terminology for alloy steels must await more experimental work to determine the nature of new structural components appearing at certain cooling rates. Likewise, the suggestions are for hypo-eutectoid steels, for the structures of hyper-eutectoid carbon steels are much more complex and their study has not yet advanced far enough for various investigators to reach agreement.

V. KOSELEV
F. POBORIL

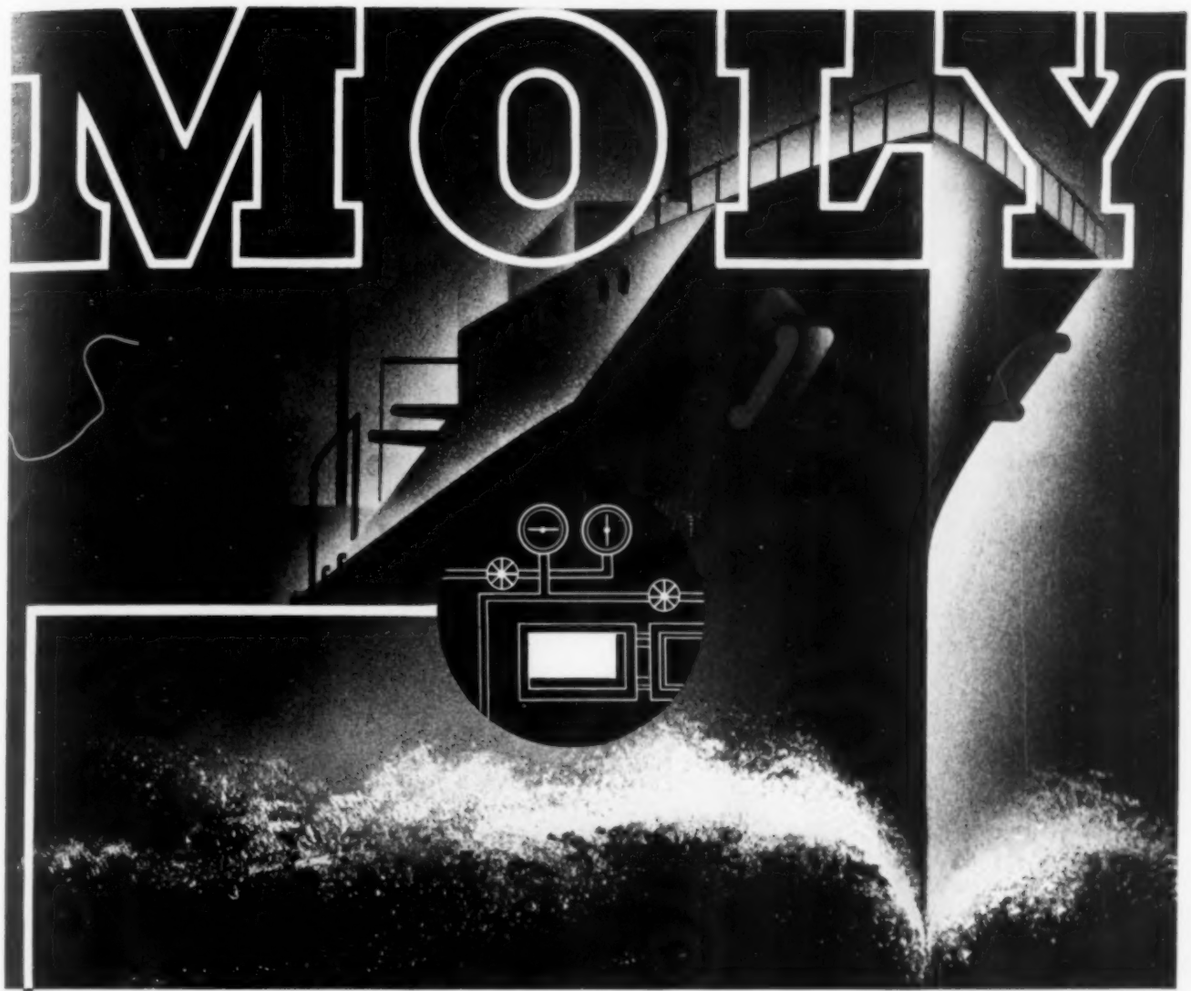
Pastes for Polishing Rapidly

CLEVELAND, OHIO — We in the Cleveland Tractor Co.'s laboratory have been much interested in experimenting with some recently developed polishing compounds for metallographic preparation. Two of these, called "H-46 Coarse" and "H-46 Fine," are thick pastes made by the Carborundum Co., and showed especial merit. The coarse grade cuts about the same as Tripoli, while the fine grade gives a finish near to that of No. 2 alumina.

We apply them to cloth covered wheels by stiff brushes. Their action is desirable, not only because of extremely fast cutting, but freedom from surface flow. However, relief polishing may occur, and inclusions do not seem to be well retained. Action of the etching agent is very rapid and clean.

Photomicrographs in the adjoining column of a few specimens surfaced with these compounds may be indicative of expected results. The monel metal, at 100 diameters, is etched with nitric-acetic-acetone; the gray iron, at 1000 diameters, is etched with nital; the cast alloy with 3% carbon, 18% Cr, 25% W, and 1% V is at

Monel Metal, Gray Cast Iron, Chromium-Tungsten Casting, and Heat Treated Stainless Steel; All Samples Polished With New Abrasive



gives vitality to high-temperature steels

PICTURE the boilers of a modern destroyer splitting the sea at top speed. Or those parts under the heavy pressures and temperatures of oil-refinery requirements. . . . "Moly" gives their steel the *extra* quality to meet extraordinary demands.

Not only is Moly the most effective economical element for raising the creep strength of steel. But it also prevents temper embrittlement, reduces blue brittleness, and intensifies the corrosion-resisting properties imparted by other alloying elements.

Example: A low carbon steel containing from 4-6% Chromium gives good corrosion resistance in oil-refining service. The addition of only .50% Molybdenum has been found to improve greatly this desirable quality and to result in increased recovery in the foundry as well as in the added virtues mentioned above.

While there are various types of steels in commercial use for which creep strength claims are made, the ones that grow in popularity are invariably those containing Moly. The effects of Molybdenum are so remarkable that there are today several foundries which, to insure the retention of their good reputation, insist on adding Moly to their steels of this type.

Keep posted on the rapid progress of Molybdenum. Let us put you on the mailing list of our periodical house organ, "*The Moly Matrix.*" A simple post-card request is all that is necessary. Write also for these interesting books: "*Molybdenum in* 1934" and "*Molybdenum in Cast Iron* — 1934 *Supplement.*" And, if you've an alloy problem of your own, our metallurgists and Detroit experimental laboratory are at your disposal in solving it. Climax Molybdenum Company, 500 Fifth Avenue, New York City. (In Canada: Railway & Power Engineering Corporation, Ltd.)

CLIMAX Mo-lyb-den-um

Correspondence and Foreign Letters

100 diameters and etched with alkaline ferricyanide; the quenched and drawn casting analyzing 0.85% C, 12% Cr, 3% Ni, and 1% Mo is at 500 diameters and is etched with aqua regia in glycerine.

We have found some work unsuited to these polishing compounds, but believe they have a definite merit in many applications.

GORDON T. WILLIAMS

SCHWEINFURT, GERMANY — Everyone who handles much sheet metal doubtless has, at some time or other, earnestly wished for some simple and dependable test for its deep drawing qualities. One of the most valuable discussions of this problem I have read was printed in METAL PROGRESS, October, 1931, in the form of an article by Thomas Dockray. Only recently Prof. D. H. Brasch of Hamburg has published a similar article concerning methods of testing and inspecting commonly met in Germany.

Tolerances as to size and weight are, of all the requirements, most readily determined and enforced. Uniformity of analysis is another important consideration. In the present state of the testing art, Prof. Brasch believes that the best information about the mechanical action of the sheets may be had, first from a hardness test, next from a tensile test, third from a bending test, and lastly from a cupping test.

While the Erichsen test is the one most used by the German fabricating industries, it gives no values which fill all the requirements of a good test. For this reason E. Siebel and A. Pomp at the Kaiser Wilhelm Institute devised a new testing method for sheet, which consists in the expansion of a circular perforation. This was described in *Stahl und Eisen*, 1929, p. 1866. Their original work showed the sharp distinction which can be drawn between deep drawing strip and stamping sheet by the new method.

Testing of Sheets for Deep Drawing

It would be very enlightening to see the results of an investigation in which a large number of samples of various manufacture and conditions were tested by both methods. Furthermore, a statistical study of the scattering of the results when tesing deep drawing sheet would be very useful.

Mr. Dockray notes that thicker sheets generally have better elongations, and this fact is also noted on some German standards (DIN 1623). However, this is contrary to my experience with first grade material. We find that soft steel sheets from 0.008 to 0.055 in. thick have 33.5 ± 1.5% elongation in 2 in. Another statistical investigation of cold rolled, annealed, and again slightly cold rolled extra deep drawing strip, 0.020 to 0.196 in. thick, gave an elongation of 37.5 ± 1.5% in 4 in., independent of the thickness of sheet. It seems to me the importance of this should be emphasized. Of course, such results may be had only with test pieces carefully prepared and tested according to standard.

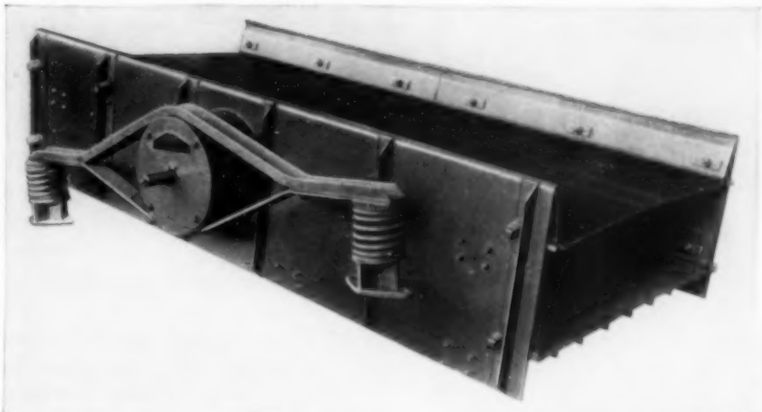
The SKF Industries, with which I am connected, also place much reliance on metallographic tests of deep drawing strip, but particularly on the bend test.

Metallographic examination of a polished cross section cut parallel to the rolling direction indicates any abnormal segregation which may be present; after a little more polishing and etching, information is had on the grain size, the uniformity of carbon distribution (at say 125 diameters) and the type of cementite at higher magnifications, say 1200 X. Incidentally, carbon content may also be estimated. Conditions are observed at the center, near the surface, and midway.

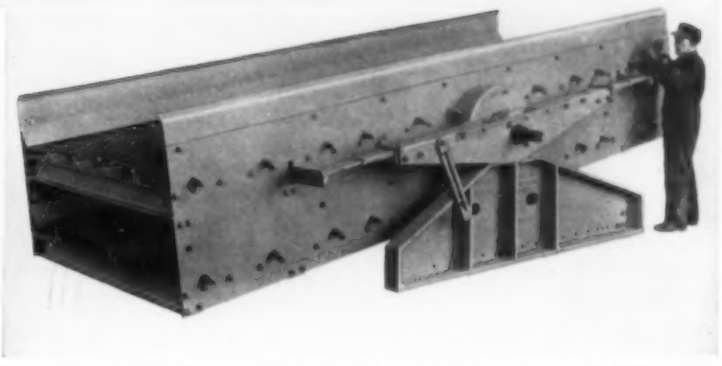
The bend test often shows great differences in materials with the same elongation and same hardness, either Brinell or Rockwell, and it has been observed in fabrication that those sheets which have a high bend value can be worked more easily than those with lower bend value, although both have the same elongation. Brittleness of material (whether caused by aging or other factors) is clearly shown, as is also any surface defect caused by gas blisters.

We perform the bend test by alternate bending 90° to the right and left over a block of 2-mm. radius for thin sheets up to 1 mm., and a block of 3-mm. radius for thicker sheets. The sample is struck with a mallet; it would be better if the

In those dependable Robins' Screens ...
Springs are Vanadium Steel



In the well-known VIBREX *Screen, made by Robins Conveying Belt Company, four coil springs of Silicon-Vanadium Steel carry the entire load of screen and material.*



Standard Double-Deck GYREX *Screen made by Robins Conveying Belt Company, 15 Park Row, New York City. Transverse springs are Chrome-Vanadium Steel.*

All over the world . . . wherever rock, ore, coal, coke and many other products are being screened . . . you'll find Robins GYREX and Robins VIBREX Screens. Playing an important part in the day in and day out performance of these Robins Screens are springs of Vanadium Steel.

In the GYREX heavy duty screen, for example, transverse springs of Chrome-Vanadium Steel carry a very large part of the total load of screen and material. They are subjected to severe stresses rapidly applied.

The four coil springs of Silicon-Vanadium Steel used in the VIBREX are subjected to stress reversals at even higher speeds. These springs carry the entire weight of the screen and its load. Only springs of Silicon-Vanadium Steel have given satisfactory performance in this service.

Since adopting Chrome-Vanadium and Silicon-Vanadium Steels for this very severe spring service, Robins Conveying Belt Company has entirely eliminated spring breakage.

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Correspondence and Foreign Letters

steel producers and fabricators could agree upon a simple bend testing fixture.

Probably the chief value of the bend test lies in the fact that it is a quasi-dynamic test, rather than the quasi-static tension test.

H. DIERGARTEN

Notes on Cupola Practice

TURIN, ITALY — Many European foundries have practically abandoned the use of cupolas, replacing them with electric furnaces, or with rotary furnaces fired with oil or pulverized coal. The latter are especially fitted for the production of iron castings of best quality.

But, notwithstanding the great advantages of these latest types, many European founders maintain that the cupola — when properly used, and if designed according to the latest improvements — can stand comparison with all other modern furnaces, both from a technical and economic point of view. In appraising this viewpoint it must be borne in mind that very few classes of technical men are so conservative as foundrymen; their opinion is undoubtedly based in part on a general dislike for change.

In fact, the "latest improvements" in European cupola design do not seem so very important. The results obtained with them during the last few years are not impressive. Nevertheless, some progress has been made in this field, and a few data concerning European cupola practice may be of some general interest.

From the point of view of design, a great number of patents have been filed in the last few years, but they are usually limited to details of construction.

The distribution of the wind through a continuous slot or through a great number of tuyeres has generally been abandoned after a few years' favor and replaced by few tuyeres, generally turned downwards. For small furnaces melting up to two tons per hour, the tuyeres are usually two in number and it can be said that the number of tuyeres generally increases with the size of the cupola, one being added for every ton-hour output.

Nearly all the devices for making various tuyeres work alternatively have also been abandoned after brief experimentation.

A double row of tuyeres, superposed and with independent control, had been adopted a few years ago by some founders. It was contended that the wind from the upper row should "regenerate CO_2 from the excess of CO eventually formed by the combustion at the level of the lower row." (This is obviously completely erroneous, when even superficially examined in the light of the chemical equilibrium between C, CO, and CO_2 existing in the cupola.) Therefore this useless complication has been abandoned.

Wind pressures vary from the very high pressures with correspondingly small tuyeres to low pressures and large tuyeres. Pressures more commonly adopted for small furnaces, of hourly capacity up to two tons, are between 10 and 16 in. water. Larger furnaces with hourly capacities of from 5 to 10 tons usually carry a wind pressure between 20 and 30 in. of water.

A great number of special designs of forehearths have recently been proposed and adopted. A typical and general feature is a syphon-shaped tube connecting the tap hole with the forehearth. This separates the slag cleanly, and relieves the forehearth of wind pressure. Advantages of such a simple device are really remarkable.

The necessity of obtaining very hot iron, when the cupola must compete with the electric or the revolving furnace in the manufacture of high strength castings, has engendered many recent efforts to improve the thermal efficiency. A special tuyere has sometimes been placed in the forehearth for overheating the molten metal. Usually the efforts have been directed toward preheating the wind. Many types of preheaters have been constructed; some of them are placed at the blower intake, some between blower and furnace. The results have been questionable. From the point of vew of purity and uniformity, the metal so obtained can hardly be compared with iron melted and overheated in an electric or in a revolving furnace.

From the point of view of coke economy, experience has proved that blast heaters do not bring notable results. *(Continued on page 66)*

for applications of Heat or Corrosion . . . . . .

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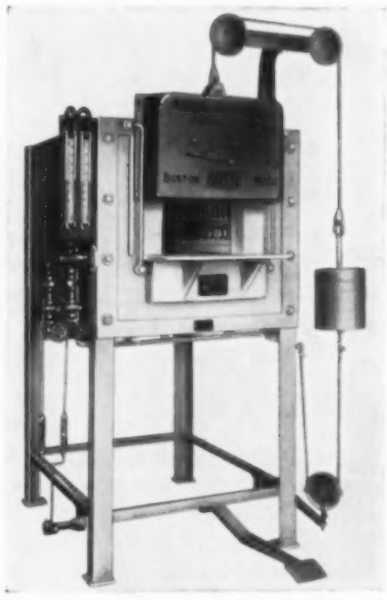

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Spring Leaves

(Continued from page 55) for one hour. Since floor space was limited, the furnaces were made 50 ft. long, and the conveyor travel is correspondingly slow.

These furnaces are heated by standard Surface Combustion convection type air heaters. Two units are mounted on the roof of each furnace, each serving one-half the length. As shown in the view on page 55 these consist of "Dutch ovens" in which the necessary amount of city gas is burned to keep the recirculating air at the correct temperature. Fans deliver this hot air to several ducts, both above and below the conveyor hearth, and appropriate flues draw the hot air off and return it to the heater. Pressure inside the furnace is maintained slightly above the outside atmosphere, so there will be no inrush of cold air at the entrance and discharge doors, and, on the other hand, it is so balanced that no blast of hot air escapes at those openings. The temperature of the draw furnace is so low that no scale is formed.

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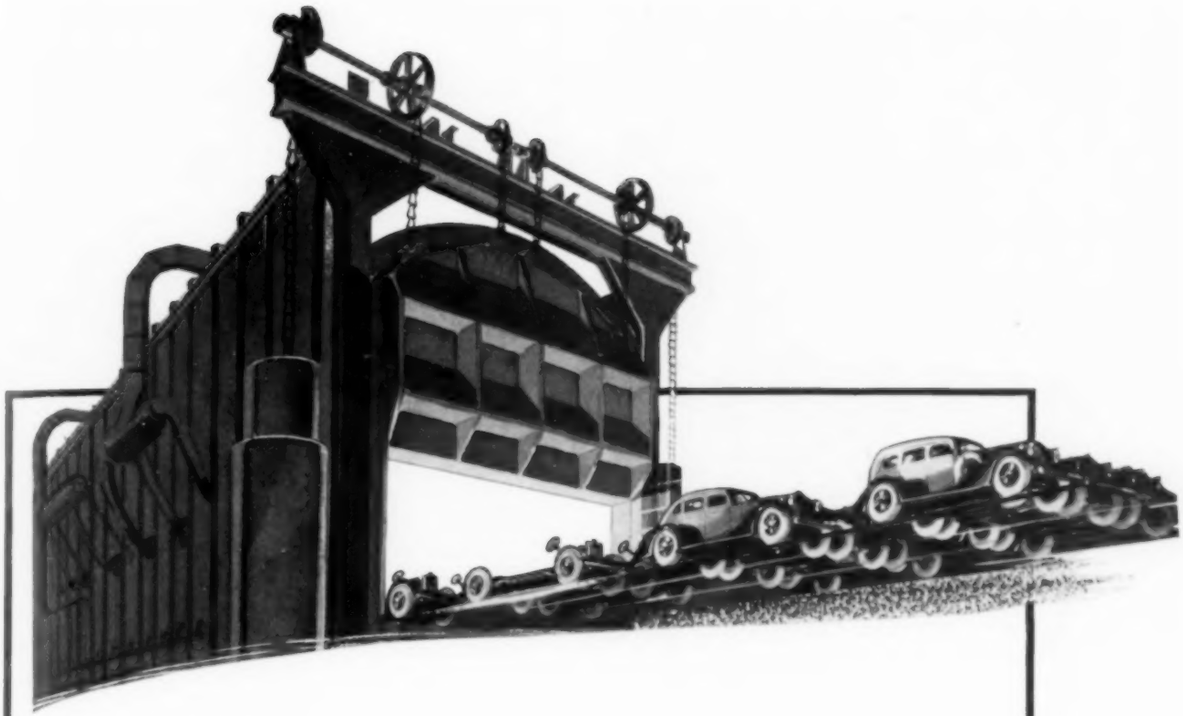
With our new hardening furnaces with controlled atmosphere and our improved drawing furnaces, we have been enabled to achieve several results in mass production which we believe are unique in plants making leaf springs:

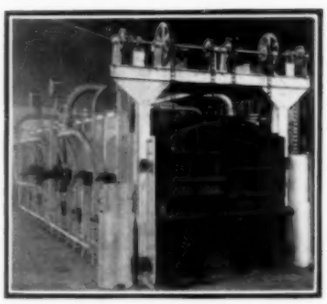
We are heating, before quenching, for unusually long times, to unusually close temperature limits, in a neutral atmosphere which does not add or subtract anything from the surface as delivered by the steel mill.

The combination of heat treatment and quenching practice, as described, produces spring leaves which are unusually uniform. For instance, we have no serious difficulty in meeting a specification as close as 444 to 461 Brinell.

Last, but by no means least, we are cambering spring leaves so accurately that hand fitting is almost eliminated, even though the thickness may be as low as 0.155 in., rather than the 0.25-in. bars which were frequently handled in the past. Absence of warpage is a certain sign of uniformity in internal structure. Elimination of hand fitting abolishes the large and unknown internal stresses induced by "setting" hardened steel leaves.



BEHIND *the scenes of* INDUSTRY



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Most owners little realize the important part played by modern furnace design in the rapid progress of the automobile industry. Vital parts are strengthened, the car as a whole can be made lighter and the wearing parts made to last longer because furnace engineers and alloy steel manufacturers have kept pace with progress.

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(Cont. from page 62) In fact, coke consumption in the latest European cupolas, when melting hot ordinary iron, very seldom goes below 8.5%, and usually reaches 9.5 to 10% of the weight of molten iron. These figures are practically the same as obtained 20 years ago with cupolas of the same size melting the same types of iron.

FEDERICO GIOLITTI

Metals of High Purity

PARIS, FRANCE — The precision attained by machinists, in the production of metallic parts, may be expressed by means of a decimal fraction of a unit of length. That is to say, the tolerance on a rough casting may be 0.100 in.; the tolerance on the diameter of a punched hole may be 0.010 in.; the tolerance on fine lathe work may be 0.001 in.; on precision grinding it may be 0.0001 in.; and only on the best of gages is it less than 0.00001 in. It has also been said by competent authority that the science of measurement increases in precision by another decimal every 50 years, and that every acquired decimal ushered in great improvements in science and applied mechanics.

In the same way, improvements in metallurgy may be expressed by means of the decimals gained in the purity of industrial metals.

As in the case of linear tolerances, purity in metal may be expressed by a decimal representing the total impurities or dross. Thus the dross in a metal like iron which is smelted at high temperatures from impure mixtures may be measured in units of 0.01 (1%); dross may be 0.001 (0.10%) in metal like tin which is smelted at lower temperatures from very pure ores; it may be measured in units of 0.0001 (0.01%) in a metal like nickel which is condensed from a vapor or gaseous carbonyl compound.

Within the last few years a considerable improvement in purity has been realized in copper, zinc, cadmium, aluminum, and magnesium by perfecting the electrolytic refining process. The best example is zinc, and is well known to you Americans, who have insisted on 99.99% purity for the manufacture of die castings. High purity magnesium and calcium (dross measured by units of 0.0001, or 0.01%) *Cont. on page 68*

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HIGH SPEED CUTTING EDGES

ON MILD STEEL ★ ★ ★ ★

Cutting tools and dies now can be made of cold rolled stock and provided with hard, tough cutting edges which last longer than high speed tool steel. The cutting edge metal is deposited on the mild steel by arc welding with the new "Toolweld" electrode. Tools so made, also tools of high speed tool steel, can be rebuilt with "Toolweld" innumerable times. The weld metal, as deposited, has a hardness of 55 to 65 Rockwell C. This hardness is retained at relatively high temperatures, up to approximately 1000 degrees Fahrenheit. "Toolweld" metal can be heat-treated in the same manner as high speed steel. The weld metal is of high density, practically free from porosity.

COMPARISON—On a lathe operation, fourteen shafts were turned to a depth of 3/16" for length of 15" by a mild steel tool faced by "Toolweld". Turning at the same speed, only six shafts could be machined 3/16" deep for 12" length by the usual high speed tool before it had to be reground. The tool of mild steel faced by "Toolweld" showed almost no signs of wear, yet it did practically three times as much cutting. On this particular operation, "Toolweld" reduced tool costs 62%.

FREE trial sample of "Toolweld" electrode with complete procedure for application is available upon request addressed to

W-119
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Correspondence

(Cont. from page 66) have also been secured in considerable quantity by distilling the best available metal.

High purity metals are therefore obtained by industrial or semi-industrial processes and which allow us to look for practical applications. In this respect it may be pointed out that two general properties, having a great practical importance, appear to be conferred on metals by high purity, *(a)* ductility and *(b)* resistance to chemicals.

Gold gives a good illustration of the former. Metal 99.8% pure may be beaten out in leaf three millionths of an inch thick. Nevertheless, if that gold contained 0.05% bismuth it would be as brittle as toast.

Dr. P. Bastien in the writer's laboratory has recently obtained some interesting results along the same line. He found that industrial magnesium (dross 0.5%) had a ductility of 10% elongation in a rolled and annealed bar; when purified by distillation (dross less than 0.001%) its elongation was 18%. Similarly, industrial calcium (dross 1.5%) in cast bars had 30% elongation; purified to 0.7% dross it had 53% elongation — a notable increase.

Everyone is familiar with the contention of wrought iron manufacturers and makers of "ingot iron" that corrosion resistance increases with the purity. This question cannot be answered categorically, but undoubtedly some very pure metals are quite insoluble in reagents which react to produce soluble compounds. (Obviously it would be unfair to test the metals in solutions which render them passive, as aluminum in nitric acid, or magnesium in hydrofluoric acid, and which result in the production of insoluble adherent salts.) Dr. Bastien has tested the magnesium mentioned above in 1% HCl in water, and finds that the rate of solution of the commercial metal is 240 mg. per sq.cm. in 10 hr., whereas the figure for purified metal is cut to 200 mg. Results are really striking for aluminum: Industrial metal (dross 0.5%) dissolves in 30% aqueous solution of HCl at the rate of 354 mg. per sq.cm. in 10 hr., whereas aluminum purified to 0.005% dross by electrolysis only loses 3 mg. in the same circumstances.

ALBERT PORTEVIN

What to read

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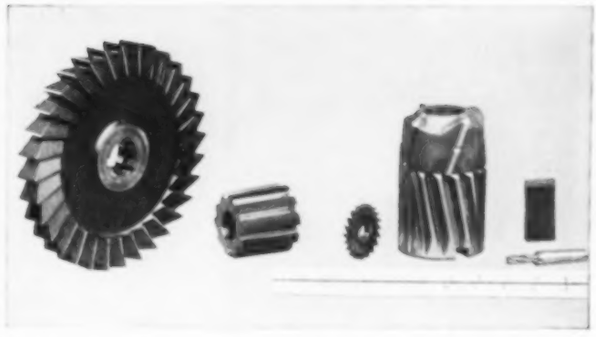
(Continued on page 72)



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Reduced Steel Bill

Savings by elimination of spoilage amount to $212 per month in the plant of a machine firm. They had about 25% spoilage formerly because all high speed tools were special and of great variety, making it impossible to harden by formula. When they installed "Certain Curtain" furnaces, they found that the precise atmosphere control gave them a "Margin of Safety." Even the most delicate tools could be held extra long at the critical without scaling, pitting or other injury. Savings in steel and other tool costs paid for this equipment in one single year!

30% more cuts between grinds

The report of another firm, a very large machine shop, is that they realize a profit of $571 per month on their "Certain Curtain" team of pre-heat and high speed. They get 30% more cuts between grinds, saving 25% of labor in the tool grinding department. They also report a 25% decrease in the cost of finished tools, including savings in steel, tool-making cost and hardening cost. This equipment repaid its cost in well under a year.

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The prime reason for the success of "Certain Curtain" hardening in comparison with other methods, is that it has the only effective control of furnace atmosphere. This patented feature eliminates surface attacks, minimizes distortion, controls grain growth. "Certain Curtain" furnaces pay for themselves—giving you better tools at less cost.

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New Homo Furnace

The new Homo furnace described in a bulletin issued by Leeds & Northrup provides for even tempering on a very dense load. Automatic control includes a feature that prevents overshooting. Fine tempering on extra dense loads at low cost is provided. Bulletin Mx-46.

Safety in Oxwelding

A revised edition of "Precautions and Safe Practices" in the care and handling of oxy-acetylene equipment has been prepared by Linde Air Products Co. This booklet is regarded as a standard reference on this phase of safety in industry, and this latest edition contains some new suggestions required by advances in the oxy-acetylene process. Bulletin Mx-63.

Tubing Weight Tables

Timken Steel & Tube Co. has issued a series of "Master Weight Tables" for round steel tubing, on letter size heavy paper, punched for binding. Weights per lineal foot of length are given for all sizes of hot finished and cold drawn tubing. Bulletin Mx-71.

High Tensile Steels

Three types of high tensile steel particularly adapted to the transportation industries are described in a folder from U. S. Steel Corp. These are a chromium-copper-silicon steel for corrosion resistance, a medium manganese steel, and a strong structural silicon steel. Bulletin Mx-79.

Box-Type Furnaces

The advantages of Hevi Duty box-type electric furnaces are concisely stated in a folder which contains specifications and a fully labeled cross-section of a representative furnace. Bulletin Mx-44.

Turbo-Compressors

The new items in Spencer Turbine Co's bulletin are a new and smaller "Midget" turbo for individual mounting, a single-stage line which effects new economies, and the gas-tight turbos for acid and explosive gases. Bulletin Mx-70.

Annealing Stampings

Operating data on a controlled atmosphere furnace for bright annealing steel stampings are given in an illustrated folder offered by Surface Combustion Corp. Among the advantages listed are economy of fuel consumption and elimination of necessity for pickling. Bulletin Mx-51.

Hardening High Speed

No spoilage when high speed steel is hardened in Certain Curtain electric furnaces, claims a recent booklet of C. I. Hayes, Inc. Grain growth is controlled and the most delicate tools develop maximum hardness without decarburization, scaling or fusion. Bulletin No-15.

The Enduro Family

A new edition of Republic's booklet on the Enduro 18-8 family of stainless steels includes among other authentic data a table showing corrosion resistance in the presence of several hundred chemicals, solutions, and other reagents. Bulletin Mx-8.

Misco Alloys

Compositions, properties, and applications of Misco stainless, heat, and corrosion resisting castings are given in an illustrated folder offered by a pioneer producer, Michigan Steel Castings Co. Bulletin Mx-84.

Carburizing Steel

High strength and ductility, forgeability, and machinability, combined with superior case carburizing properties permit the attainment of maximum production with minimum cost. Such properties are obtainable in Jones & Laughlin's Jalcase steel. Bulletin Mx-50.

Controlled Steels

Carnegie Steel Co. has published a very interesting booklet which describes in some detail the process control used in the production of uniform steels. Bulletin Je-85.

New Joining Process

Metal parts are joined cheaply, neatly and strongly by Electric Furnace Co.'s new, inexpensive non-oxidizing furnace atmosphere and their new, continuous brazing, coppering and soldering furnaces. Full details are given in Bulletin Ar-30.

Coated Electrodes

Murex heavy mineral coated electrodes are the subject of a well-conceived booklet prepared by Metal & Thermit Corp. Emphasis is laid on the metallurgical merits of a heavy, all-mineral coating. Many practical hints on welding are included. Bulletin Jr-64.

Cyanides and Salts

R & H Chemicals Department of E. I. du Pont de Nemours Co. has a new 28-page manual on the procedure for case hardening, reheating, nitriding, and mottling of steels with cyanides, and on coloring, tempering, and drawing with salts. Nv-29.

Quenching Handbook

E. F. Houghton & Co. have published an excellent 80-page handbook on the subject of quenching. More than 30 charts and photomicrographs help tell the story. A copy will be sent free to those who request it. Bulletin JI-38.

Cast Vanadium Steel

Jerome Strauss and George L. Norris have written a technical booklet for Vanadium Corp. of America describing the properties developed by steel castings containing various percentages of vanadium. Bulletin S-27.

High Strength Steel

Cromansil steel, a development of Electro Metallurgical Co., has high strength and good ductility "as rolled" and is thus fine for structural applications where its great strength saves much dead weight. Bulletin Je-16.

Blast Cleaning

A centrifugal machine which cleans castings without the use of compressed air is the subject of Pangborn Corporation's new folder. How and why 1800 lb. of castings can be cleaned in 8 min. at low cost is told. Bulletin Jx-68.

Photocell Pyrometers

Recording potientiometers using a beam of light, a mirror galvanometer, and a photo-electric cell give instantaneous control with high sensitivity and accuracy. The different varieties made by C. J. Taglibue Mfg. Co. are described in a 16-page letter-size booklet. Bulletin Fx-62.

Electric Furnaces

A wealth of information on controlled atmosphere electric furnaces is contained in General Electric Co.'s booklet by that name. Detailed data are given on electric brazing in particular. Bulletin Jx-60.

Nickel Cast Iron's Uses

The role of nickel and nickel-chromium cast iron parts in such applications as fabricating sheet metal, pressing and forging is interestingly explained in a new pamphlet of International Nickel Co. Bulletin Ag-45.

Metallograph

A new 36-page booklet of E. Leitz, Inc., contains all information on the Leitz large Micro-Metallograph, MM 1. Excellent photomicrographs are reproduced to show its capacity. Special attention is given to the darkfield illumination feature. Bulletin Se-47.

Tempering Furnace

Technical details and operating data on Lindberg Steel Treating Co.'s new Cyclone electric tempering furnace, which has shown a remarkable performance record in steel treating operations, are given in Bulletin Fx-66.

Shielded Arc Welding

Lincoln Electric Co. offers a very fine descriptive booklet describing the process of welding with a shielded arc. Text and illustrations are designed to acquaint engineers with the possibilities of the process. Bulletin Ob-10.

Phosphor Bronze

American Brass Co. tells why Anaconda "Special" phosphor bronze can be used advantageously for bushings, bearings, gears, and other screw machine products. It is a truly free-cutting alloy and does not foul cutting tools. Other properties are given in this new edition of their booklet. Bulletin Fx-89.

Molybdenum in 1934

Climax Molybdenum Co. presents their annual book giving new developments in molybdenum, particularly as an alloy with iron and steel. The engineering data presented are made clear by tables and illustrations. Bulletin Dc-4.

Dark Room Layout

A novel card 9½x13 in. containing suggested arrangements for a photomicrographic dark room has been designed by Bausch & Lomb. Costs for installation are estimated, and on the reverse side are printed rules for using the dark room. Bulletin Jx-35.

Radium Radiography

Advantages of portability, ease of application and manipulation in examination of castings, forgings, molds, weldings, and assemblies are attributed to radium for industrial radiography. Details are given in a booklet issued by Radon Co. Bulletin Jx-56.

Neophot

"Neophot" is the name of a new metallograph of radically new design and universal adaptability. A pamphlet distributed by Carl Zeiss, Inc., gives its applications and features and is well illustrated with beautiful samples of micrographic work. Bulletin Jx-28.

Fast-Cutting Steel

Bliss & Laughlin, Inc., offer an interesting technical folder on Ultra-Cut Steel, giving performance records of this high-speed screw stock on automatic screw machines. Physical data and microstructures are presented. Bulletin Ob-42.

Foundry Pyrometer

A leaflet from Pyrometer Instrument Co. briefly tells the advantages and operation of their Pyro Immersion Pyrometer for foundry use. This compact, self-contained instrument can be operated with one hand. Bulletin Fx-37.

Cold Drawn Shapes

Many applications of cold drawn squares and flats are enumerated by Union Drawn Steel Co. in this folder. Sizes, grades of finish, and compositions available are listed. Nv-83.

Pre-Heating Furnace

General heat treating operations up to 1900° F., pre-heating of high speed steel, annealing and firing of glass are some of the applications listed in American Electric Furnace Co.'s folder on their new model B-20 furnace. Bulletin Jx-2.

Heat Resisting Alloys

Authoritative information on alloy castings, especially the chromium-nickel and straight chromium alloys manufactured by General Alloys Co. to resist corrosion and high temperatures, is contained in Bulletin D-17.

Manual of Pyrometry

Brown Instrument Co. offers an elaborate manual which describes the 50 exclusive features of their potentiometer pyrometer. The book will greatly interest those who must maintain accurate temperature. Bulletin Jr-3.

Big-End-Up

Gathmann Engineering Co. briefly explains the advantages of steel cast in big-end-up ingots, showing the freedom from pipe, excessive segregation and axial porosity. An 82% ingot-to-bloom yield of sound steel is usual. Bulletin Fe-13.

Localized Heat Treating

American Gas Furnace Co. offers information on production machines for localized hardening, tempering or annealing of tools, saws, springs, screws and machine parts of all kinds, using gas as fuel. Bulletin Ag-11.

Heat Treating Manual

A folder of Chicago Flexible Shaft Co. contains conveniently arranged information on heat treating equipment for schools, laboratories and shops, and also illustrates the several types of Stewart industrial furnaces. Bulletin Ar-49.

Aluminum Alloys

Working facts on aluminum — the properties and heat treatment of both cast and wrought alloys — are briefed for the manufacturer and designer in a booklet by Aluminum Co. of America. An appendix gives tables of physical properties, forms and sizes available. Bulletin Dc-54.

Recuperators

Results obtained with Carborundum Company's recuperators using Carbofrax tubes are fuel savings, closer temperature control, faster heating, and improved furnace atmosphere. Complete engineering data regarding application to various types of furnaces are given in Bulletin Fx-57.

Sheffield Steels

Wm. Jessop & Sons, Inc., have a booklet which tells why a special anneal and a proper balancing of carbon, manganese and tungsten combine to make Sheffield Superior oil hardening steel non-distorting and easily machinable. Bulletin Jn-61.

Testing with Monotron

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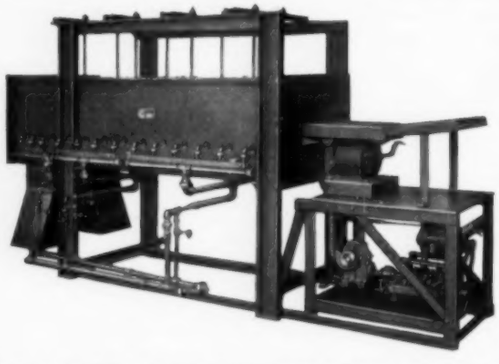

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Manganese	1.26%	Elongation in 2"	22%
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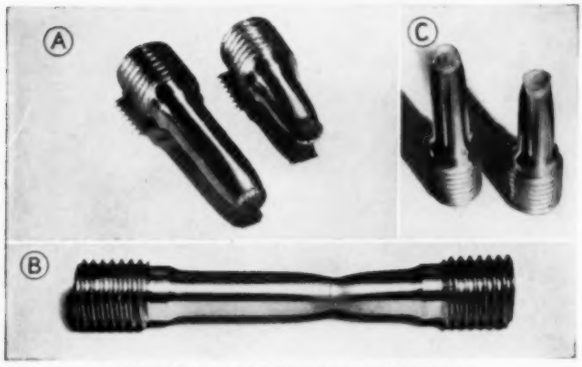

PHOTOS A & B: PHYSICAL PROPERTIES
Tensile Strength—99,500 p.s.i. Yield Point—93,500 p.s.i.
Elongation in 2"—21%

PHOTO C: PHYSICAL PROPERTIES
Tensile Strength—80,500 p.s.i. Yield Point—74,750 p.s.i.
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Age Hardening

cast condition? I refer to the nickel bronzes.

The ordinary tin bronzes containing up to 10% of tin are not appreciably hardened in the way we are discussing — and this may be ascribed chiefly to the fact that there is little change in the solubility with temperature of the delta phase in the alpha phase. When 3 to 4% nickel is added, a remarkable change takes place in this solubility curve, and, although the solubility at higher temperatures — say around 700° C. (1300° F.) — is little altered, that at lower temperatures is lowered from about 12% to about 2% of tin. In consequence the nickel-treated bronze is rendered age hardenable. Here is a case in which a non-hardenable alloy, by a mere distortion of its temperature-solubility relations, is transformed into an "aging" one. (Structural diagrams are shown on page 50.)

The conveniently hardenable range comprises those alloys containing from 3 to 10% of tin and from 3 to 10% of nickel. Within this range their properties vary somewhat, but choosing an alloy containing 8% tin and 7.5% nickel as a representative one, the following properties are characteristic of the sand cast alloys:

	As Cast	As Treated
Proportional limit	25,000	50,000
Tensile strength	55,000	90,000
Elongation	18	15
Reduction of area	18	25
Hardness	100	175

The heat treatment consists usually of annealing and quenching from about 1400° F. followed by tempering at about 600° F., although air cooling will suffice for the first treatment of small castings.

Their value lies primarily in the excellent mechanical properties possessed by alloys which can be handled by the brass foundry, and which possess casting properties (and particularly high proportional limits) comparable with the ordinary foundry bronzes. Incidentally, these same alloys after casting can be readily cold rolled and exhibit, as one would expect, even better properties in the rolled and heat treated condition than as cast. Tensile strength values of over 125,000 psi. are possible in such alloys when rolled and heat treated.